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Some Aspects of the Blast-Furnace Situation in the United States

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SYNOPSIS

Factors concurrent with and contributing to the present high level of production from United States blast-furnaces are enumerated and discussed. Operation statistics for more than 100 furnaces in the northern and southern states are tabulated, and are analysed and compared in the light of a rating formula based on the amount of coke burnt per day per square foot of an annulus 6 ft. inwards from the tuyeres; comparable data for British and other blast-furnaces are also presented. Ore and coking-coal resources available to the United States ironmaking industry are evaluated, and refractory materials, including carbon hearths and linings, are reviewed. Subsequent to consideration of high-top-pressure operation and experiences with oxygen-enriched air, trends in furnace design, construction, equipment, manning, and costs are indicated.

THE centre of focus of the American blast-furnace picture today is massive production. Nine new units are in course of erection, at least six more are under serious consideration, many relatively small furnaces are being enlarged within the limits of existing steelwork, and furnaces are being driven at the maximum rate compatible with quality of product and rational practice. Concurrent with the efforts towards high productivity and contributing to its achievement are factors such as (1) increased attention to the beneficiation of raw materials, (2) improvements in refractories, leading to reduction of furnace rehabilitation, (3) investigation of technological innovations, (4) continuous improvements in design, construction, and accessory equipment, and (5) the employment of capable technicians, metallurgical assistants, and suitably educated scale-car operators and stove tenders. Over all is the factor of economics, which, while perhaps not so overriding a feature as in other days, requires that in the drive towards high production there is no flagrant indifference to the coke consumption per ton of pig, gas credits, dust recovery, number of personnel, or expense of equipment.

It is the object of the present paper to review and amplify a number of such features and other aspects characterizing the prevailing blast-furnace situation in the United States. Certain items will be considered in some detail, but it will be realized that exhaustive consideration of the many factors involved is impracticable within the limits of the present review.

PRODUCTION AND FURNACE-SIZE DEVELOPMENT

Production from United States blast-furnaces in the early months of 1951 was at the rate of approximately 69,000,000 short tons per year, compared with an output of 66,100,000 tons of pig iron and ferro-alloys during 1950. The average annual productions for the two previous five-year periods back to 1940 were 54,760,000 and 57,300,000 tons, respectively. The present average daily production per furnace is approximately 950 tons.

In 1944 the average hearth diameter of a group of 75 furnaces was 22 ft. 3 in. and the average volume was 33,897 cu. ft. In 1950 the average hearth diameter of the same group was 23 ft. 3 in. and the average volume was 36,043 cu. ft., an increase of more than 6% in six years. Data for a specimen from this group are presented in Table I and are typical of the change.

RATING AND OPERATING STATISTICS

Blast-furnace rating is a significant factor and is of

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Table I

TYPICAL ENLARGEMENTS OF AMERICAN BLAST-FURNACES DURING 1944–50

Furnace	Hearth Diameter		Volume, Iron Notch to Bell, cu. ft.	
	1944	1950	1944	1950
1	20 ft. 6 in.	20 ft. 6 in.	28,742	28,742
2	20 ft. 6 in.	28 ft. 0 in.	28,642	54,860
3	21 ft. 3 in.	28 ft. 0 in.	29,831	54,860
4	25 ft. 6 in.	25 ft. 6 in.	39,737	40,090
5	25 ft. 0 in.	25 ft. 6 in.	39,140	40,099
6	25 ft. 0 in.	25 ft. 0 in.	38,273	38,967
Average	22·96 ft.	25·40 ft.	34,061	37,602
Increase	...	10·6%	...	10·3%

interest to blast-furnacemen everywhere. A rating yardstick should have a reasonable degree of wide applicability, and in this respect a rating based on iron output is inadequate ; an 800-ton furnace at, for instance, Sparrows Point is not necessarily an 800-ton furnace in Jamshedpur or Margam.

The blast-furnace is fundamentally a coke-burner, and any given hearth will, or can, account for a certain amount of coke per day. A serviceable yardstick for blast-furnace rating comparison is provided by the formula of 6300 lb. of coke of 86% carbon (*i.e.*, 5400 lb. of carbon) per day* per square foot of the annulus 6 ft. in front of the tuyeres. Thus at 100% rating a furnace with a 20-ft. hearth should account for about 1,460,000 lb. of coke per day, and a 25-ft. hearth should account for 2,050,000 lb. of coke per day. Figure 1 is a graphic expression of the rating formula 100% rating $= 6300 \times 18{\cdot}85\,(D - 6 - 1{\cdot}5)$ lb. of coke per day, where D is the hearth diameter, the diameter of the tuyere-nose circle being generally the hearth diameter minus about 1·5 ft. This is the formula that will be used in rating calculations throughout the present paper.

Operating data for 107 blast-furnaces in the United States for the year 1950 are tabulated in Table II, the rating for each furnace in terms of the formula presented being included. As the furnaces listed, located at 28 plants of nine companies, represent about 45% of the working units in the country, they can be considered as constituting a reasonably competent sample of blast-furnace operation in the United States for the year concerned. It should be understood, however, that references in the present paper to ' all ' United States blast-furnaces can be accurate only within the limits of competency of this sample. In Table III similar operating data for a number of British blast-furnaces are listed, and Table IV gives comparable figures for blast-furnaces in the Netherlands, South Africa, India, and Brazil ; the data in Tables III and IV are not limited to the year 1950.

All the furnace ratings, in terms of pounds of 86% carbon coke charged per day, given in Tables II, III, and IV are shown graphically in Fig. 2, in which the rating-formula graph is also reproduced, and in Table V operation particulars for the rating groupings of the furnaces listed in Table II are averaged. It will be seen that the average rating of United States blast-furnaces is 95·7%, and that about 60% of the units operate at 90–105% rating, 14% at over 105% rating, and 26% at under 90% rating ; the average cumulative production of the furnaces in the last-mentioned grouping shows that the linings concerned are older. The data also show that southern furnaces operate at considerably higher ratings than those in the north, and that coke consumption per ton of pig does not seem to be affected until the rating exceeds 100%, when a substantial increase in the coke rate takes place : that vigorous ratings up to 100% do not seem to prejudice coke consumption is an important point worthy of emphasis. Collected operating data for British, Netherlands, South African, Indian, and Brazilian furnaces are similarly presented in Table VI.

An outstanding feature emerging from a study of Tables V and VI is the comparatively low average rating for British furnaces ; no apparent influence coincident with this appears in these tables, but one factor not listed may be significant, namely that the average blast pressure at British furnaces appears to be about 13 lb./sq. in. (*see* Table III), whereas, as shown in Table VII, the average blast pressure at northern United States furnaces (94% rating) is approximately 18·6 lb./sq. in., and that for southern United States furnaces (116% rating) is about 23 lb./sq. in. The days when blast-furnace operation in the United States was subordinated to the capacity of the blowing equipment are past, the equipment now, in general, being adequate to supply the rated blast volume at whatever pressure the operator is willing to permit—and he is rarely alarmed at pressures in the region of 20 lb. This is particularly so in the South, where it is not unusual for pressures to approach 30 lb. It is true that the southern furnaces hang and that it is routine practice to check them virtually on schedule about every 20 min., but the theoretical time loss is overshadowed by the practical benefit resulting : these furnaces have the highest rating in the country, higher daily throughput of materials, and, although working on relatively lean ores and high slag volume, produce pig iron in quantities comparable to many more favoured northern furnaces. The crux of the matter is the maintenance of blowing volume reason-

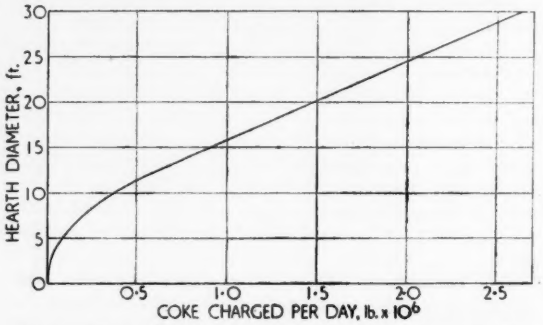

Fig. 1—Blast-furnace rating on basis of consumption of 6300 lb. of coke (86% carbon) per day per square foot of annulus 6 ft. inward from the tuyeres

* A day is taken as 1420 wind-on minutes.

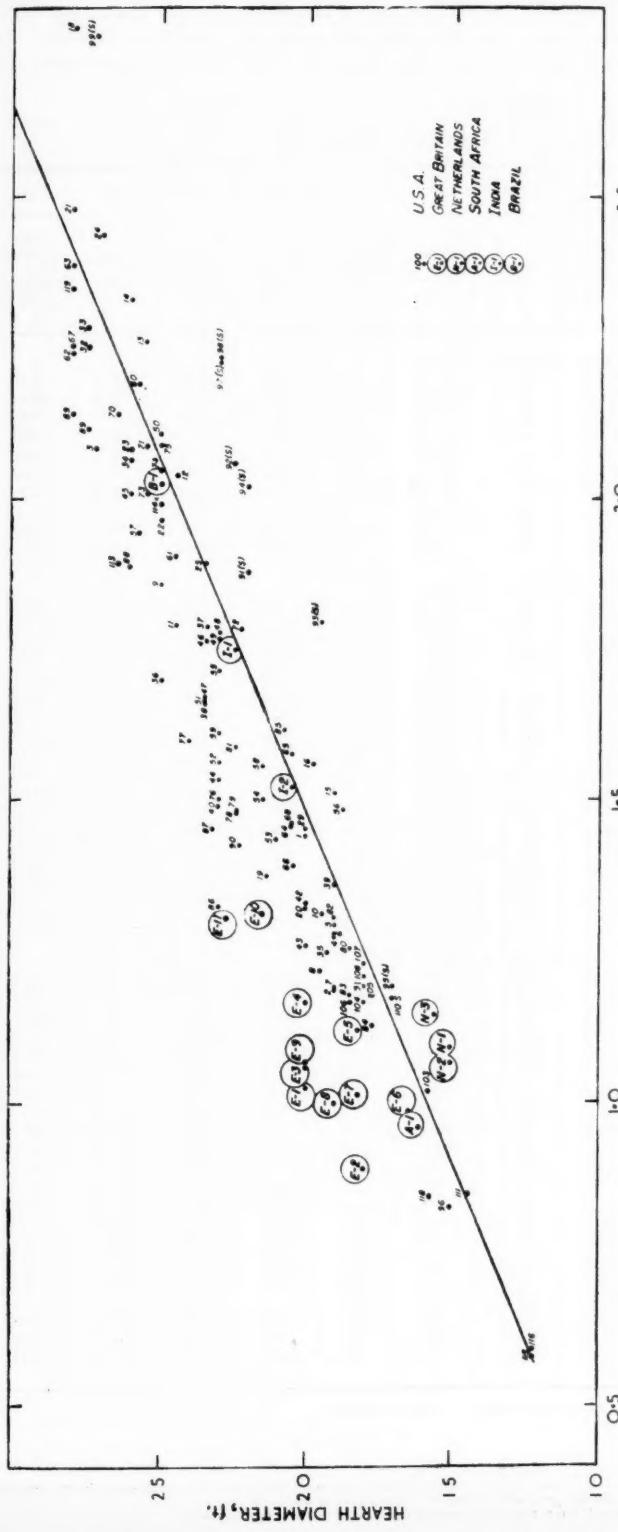

Fig. 2—Actual furnace ratings

ably unprejudiced by blowing pressure, and an outstanding authority on blast-furnaces has recently suggested* that the northern operators would gladly abandon their scruples in regard to 20-min. checking if, through adoption of the practice, blast rates as high as those attained in the south could be successfully carried. The present author is diffident in venturing the suggestion that British furnacemen might find some elements in southern United States practice, particularly with respect to blast and its manipulation, which might beneficially apply to increasing furnace rating and iron output ; it is possible that such measures have been tried and found incompatible with British conditions.

A few more averaged statistical quantities in regard to United States blast-furnaces are as follows : At the end of 1950, the average United States blast-furnace had produced about 895,000 tons on its existing lining, 35% of the furnaces had apparently produced 1 million tons or more, 10% had produced 1½ million tons or more, and 4% had made over 2 million tons. Average daily productions are : Furnaces with 27–28-ft. hearths, 1348 tons ; 25–27-ft. hearths, 1128 tons ; 22–25-ft. hearths, 937 tons ; 20–22-ft. hearths, 791 tons ; 18–20-ft. hearths, 730 tons. Data in regard to production, coke rate, and rating of furnaces of various size groups are graphically presented in Fig. 3.

Blast Temperature

In 1950 the average blast temperature at 107 United States blast-furnaces was 1020° F. At 95 northern furnaces the average temperature was 1000° F., but if a group of eight furnaces operating chiefly on imported hard-hematite ore be excluded, the northern average is 975° F. The hard-hematite furnaces referred to employed an average blast temperature of 1390° F., and at seven of them, producing basic iron, the average blast temperature was 1430° F. Southern furnaces carried an average blast temperature of 1135° F. (1430° F. for basic iron).

* C. G. Hogberg, *Iron Steel Eng.* 1950, vol. 27, pp. 37–54.

The contrast between blast temperatures at northern furnaces and the hard-hematite and southern furnaces is striking, in some cases amounting to the conservative equivalent of 100 lb. of coke per ton of pig, worth possibly $200,000 a year on a 1000-ton furnace.

The condition of low blast temperatures has

Table II

UNITED STATES BLAST-FURNACE DATA, 1950

1	2	3	4	5	6	7	8	9	10	11	12	13
Furnace Code No.	Hearth Dia. Ft. In.	Potential* Coke per Day, lb. × 10^3	Pig per Day, tons	Coke† per Ton Pig, lb.	Coke per Day, lb. × 10^3	Rating, %	Slag Volume, lb./ton pig	Dust, lb./ton pig	Sinter, lb./ton pig	Blast Temp., °F.	Percent Si > 1·25%	Iron Production on Current Lining, tons × 10^3
					Less than 85% Rating							
19	21 3	1620	771	1775	1370	84·4	1238	183	Nil	1083	27·3	330
40	23 0	1820	793	1892	1492	81·8	1000	129	325	1136	12·8	1059
36	25 0	2050	915	1893	1698	82·8	1000	180	167	953	60·9	945
44	23 0	1820	885	1730	1530	84·0	1000	200	352	974	26·6	1283
76	23 0	1820	832	1805	1500	82·5	1000	174	630	976	48·2	1858
77	24 0	1935	890	1785	1595	82·5	1000	159	341	1057	54·0	84
90	22 3	1730	862	1650	1420	81·8	1000	129	526	960	46·0	1231
113	26 6	2230	1140	1654	1885	84·6	1000	...	...	875	...	...
86	23 0	1820	799	1640	1315	72·2	950	225	712	998	81·8	767
87	23 3	1840	915	1585	1450	78·7	950	97	545	1042	44·4	1380
					85·0–89·9% Rating							
2	19 0	1350	704	1689	1181	87·3	1050	236	1700	875	...	667
7	19 0	1350	654	1805	1183	87·6	1050	259	1700	870	...	1057
8	19 6	1410	643	2040	1210	85·6	1040	174	1400	1000	53·1	556
11	24 6	2000	1122	1585	1780	89·0	1023	321	Nil	1120	61·0	979
36	23 6	1870	894	1850	1655	88·7	1000	155	202	790	48·9	1213
43	20 0	1460	704	1780	1250	85·8	1000	174	372	1000	23·4	591
47	23 6	1870	1016	1652	1677	89·0	1000	134	210	1113	22·0	1424
51	23 6	1870	988	1690	1670	89·4	1000	194	310	1065	31·0	2084
52	23 0	1820	958	1630	1560	85·7	1000	134	318	967	48·7	904
53	21 0	1590	805	1775	1430	89·9	1000	302	Nil	988	45·7	1743
59	23 0	1820	830	1955	1605	87·7	950	230	Nil	871	93·9	1415
69	28 0	2400	1268	1690	2130	89·0	900	115	1018	930	6·4	1363
78	22 5	1740	811	1820	1480	85·2	1000	120	788	996	48·9	289
79	22 5	1740	849	1750	1485	85·5	1000	193	315	1065	47·7	952
83	18 6	1300	630	1855	1170	86·7	1050	237	390	1009	37·4	889
88	26 0	2170	1072	1750	1880	86·8	900	167	27	897	51·1	1748
106	18 6	1290	691	1618	1160	89·7	850	125	684	940	...	878
118	15 9	980	498	1671	834	85·0	...	116	Nil	...	...	...
					90·0–94·9% Rating							
3	27 2	2300	1241	1670	2080	90·4	950	130	1700	800	...	427
4	19 0	1350	793	1600	1272	94·4	950	153	1700	825	...	1081
6	19 0	1350	777	1645	1279	94·6	950	190	1700	825	...	1215
9	25 0	2050	1221	1515	1847	90·1	1006	107	1400	1006	2·2	263
10	19 6	1410	777	1680	1305	92·4	1021	140	1400	1021	2·3	372
20	20 0	1460	715	1841	1315	90·1	1081	182	Nil	1088	57·4	634
35	19 3	1380	667	1873	1245	90·4	1000	155	15	995	77·8	827
42	20 0	1460	731	1810	1320	90·5	1000	127	320	1106	12·8	279
45	26 0	2170	1262	1580	2000	92·2	1000	225	57	1148	24·3	687
46	23 6	1870	1082	1630	1765	94·4	1000	195	215	1087	18·4	1347
54	21 6	1650	897	1685	1500	91·3	950	121	12	995	84·1	557
55	23 0	1820	928	1850	1710	93·8	950	127	Nil	911	27·8	1180
57	25 9	2150	1176	1670	1935	90·2	950	142	Nil	1000	21·3	109
58	21 6	1650	891	1750	1560	94·9	950	143	Nil	967	86·1	469
61	24 6	2000	1025	1845	1898	94·9	900	233	Nil	918	89·8	1219
62	28 0	2400	1304	1705	2230	92·9	900	316	1420	896	45·1	1043
66	20 6	1530	760	1825	1385	90·8	900	250	Nil	891	56·4	69
67	28 0	2400	1314	1710	2240	93·6	850	83	6	992	6·0	269
81	22 6	1750	905	1758	1585	90·7	850	263	Nil	1103	87·5	889
89	27 6	2340	1350	1570	2110	90·5	950	151	Nil	1036	22·7	920
96	15 0	900	450	1800	825	90·2	900	108	1636	1321	95·2	341

* According to rating formula † 86% Carbon

Notes : Column 3. Values taken from Fig. 2.
Column 6. Values from column 4 × column 5
Column 7. Values from (column 6 ÷ column 3) × 100
Column 8. Values in round figures are approximate (probable error ± 5%)
Column 9. Dustcatcher dust only. Some values are actual reported dustcatcher figures, while others are calculated from reported figures which include washer sludge (probable error of calculated values ± 10%)
Column 10. Values in round figures are calculated from reported percentage sinter in total ore burden

Table II—*continued*

1	2		3	4	5	6	7	8	9	10	11	12	13
Furnace Code No.	Hearth Dia. Ft.	In.	Potential* Coke per Day, lb. × 10^3	Pig per Day, tons	Coke† per Ton Pig, lb.	Coke per Day, lb. × 10^3	Rating, %	Slag Volume, lb./ton pig	Dust, lb./ton pig	Sinter, lb./ton pig	Blast Temp., °F.	Percent Si > 1·25%	Iron Production on Current Lining, tons × 10^3
						95·0–99·9% Rating							
1	20	0	1460	803	1784	1441	98·0	1050	190	1700	925	...	1486
5	19	0	1350	733	1750	1290	95·9	1050	137	1700	900	...	151
22	25	0	2050	1042	1855	1965	95·7	1223	221	Nil	984	21·6	1083
23	26	0	2170	1096	1892	2075	95·5	1106	211	650	961	12·7	349
29	20	0	1460	764	1900	1450	99·2	991	232	1700	932	13·5	1604
31	18	0	1230	643	1840	1183	96·0	1040	155	1700	900	11·2	846
32	27	6	2340	1252	1795	2240	95·9	1000	262	164	938	28·7	2846
33	27	6	2340	1448	1590	2280	97·7	1000	218	166	1000	20·0	161
34	26	0	2170	1187	1740	2060	95·1	1000	177	436	1037	20·4	2213
37	23	6	1870	1015	1760	1785	95·5	1000	146	263	1004	25·2	926
48	23	0	1820	967	1332	1770	97·2	1000	168	237	1148	41·6	611
49	23	0	1820	951	1850	1760	96·6	900	294	150	1134	52·4	1732
63	28	0	2400	1393	1710	2380	99·0	900	161	1418	931	33·8	974
64	20	6	1530	806	1800	1450	95·0	900	182	Nil	957	88·8	516
68	20	6	1530	785	1855	1455	95·4	900	132	Nil	984	76·4	438
70	26	6	2230	1117	1915	2130	95·5	850	184	374	752	25·1	1621
71	25	6	2100	1117	1870	2080	98·7	850	130	742	971	2·9	899
73	25	6	2100	1034	1880	2000	95·2	900	137	720	892	4·8	1587
74	25	0	2050	1071	1905	2040	99·4	850	165	547	909	18·5	228
80	18	6	1300	723	1713	1245	95·8	900	163	Nil	1063	66·2	563
82	19	0	1350	704	1850	1300	96·1	1000	155	407	1052	28·3	398
84	17	9	1200	556	2080	1155	96·2	850	159	Nil	858	36·8	921
104	18	0	1290	663	1735	1160	96·0	850	144	832	960	...	1448
105	18	0	1290	653	1753	1185	95·5	850	275	846	970	...	647
107	18	0	1290	732	1630	1220	98·2	1055	48	...	1175	...	...
108	18	0	1290	709	1666	1200	97·0	1055	...	...	1081	...	...
114a	25	0	2050	1358	1458	1978	96·4	...	93	1500	...	...	...
119	28	0	2400	1405	1697	2357	98·2	...	94	...	...	...	1000
						100–104·9% Rating							
12	24	6	2000	1190	1701	2030	101·7	1163	272	Nil	1371	2·3	979
21	28	0	2400	1370	1804	2470	103·0	1040	240	Nil	829	4·8	319
25	22	6	1750	937	1950	1820	103·0	1224	468	1700	891	58·6	2160
39	19	0	1350	700	1912	1350	100·0	1000	100	356	1013	12·8	962
50	25	0	2050	1203	1926	2100	102·2	900	308	176	1066	58·3	929
60	25	9	2150	1107	1970	2180	101·4	900	276	72	910	85·0	219
65	20	6	1530	817	1923	1570	102·5	850	129	Nil	946	79·2	565
72	22	3	1730	884	2000	1770	102·3	850	97	Nil	1004	71·8	1435
75	25	0	2050	1014	2060	2080	101·7	950	172	85	895	13·7	809
103	15	9	980	638	1585	1015	103·4	975	78	1365	1148	53·7	741
111	14	6	804	398	2090	830	103·0	900	...	...	1025	100·0	...
115	12	3	575	333	1725	574	100·0	...	53	Nil	...	...	...
116	12	3	575	318	1823	580	101·0	...	66	Nil	...	...	...
85	20	9	1570	825	1950	1610	102·8	850	128	Nil	948	64·4	222
110‡	17	0	1120	512	2273	1164	104·0	2000	85	...	...	...	...
						More than 105% Rating							
13	25	6	2100	1298	1752	2255	107·4	1160	165	Nil	1434	2·3	438
14	26	0	2170	1383	1680	2320	107·2	1160	124	Nil	1496	0·7	423
15	19	0	1350	865	1742	1505	111·6	1160	212	Nil	1377	2·7	1267
16	19	9	1450	908	1708	1550	106·9	1160	215	Nil	1438	3·1	509
18	28	0	2400	1633	1690	2760	114·9	1160	206	Nil	1470	0·6	1438
24	27	0	2290	1358	1785	2425	106·1	977	169	1800	894	8·2	874
56	18	9	1330	695	2130	1485	111·8	...	48	Nil	915	82·7	1039
91‡	22	0	1710	904	2070	1870	109·6	2000	129	961	1195	3·6	889
92‡	22	6	1750	1058	1950	2050	117·5	2000	119	902	1184	2·3	783
93‡	19	6	1410	786	2280	1790	127·0	2000	113	918	1183	8·5	991
94‡	22	0	1710	1036	1960	2010	117·8	2000	124	929	1174	2·6	205
95‡	17	0	1120	951	1990	1180	105·8	2000	148	1338	1154	29·6	615
97‡	23	0	1820	908	2440	2220	121·8	2000	145	1005	1005	0·3	155
98‡	23	0	1820	954	2350	2250	123·2	2000	91	1035	1035	0·4	1133
99‡	27	3	2320	1250	2190	2750	118·2	2000	239	1020	1020	0·6	586

* According to rating formula † 86% carbon ‡ Southern furnace

Notes: Column 3. Values taken from Fig. 2
Column 6. Values from column 4 × column 5
Column 7. Values from (column 6 ÷ column 3) × 100
Column 8. Values in round figures are approximate (probable error ± 5%)
Column 9. Dustcatcher dust only. Some values are actual reported dustcatcher figures, while others are calculated from repo figures which include washer sludge (probable error of calculated values ± 10%)
Column 10. Values in round figures are calculated from reported percentage sinter in total ore burden

Table III—BRITISH BLAST-FURNACE DATA

1	2	3	4	5	6	7	8	9	10	11	12
Furnace Code No.	Hearth Dia. Ft. In.	Potential* Coke per Day, lb. × 10^3	Pig per Day, tons	Coke† per Ton Pig, lb.	Coke per Day, lb. × 10^3	Rating, %	Slag Volume, lb./ton pig	Dust, lb./ton pig	Blast Temp., ° F.	Blast Pressure, lb./sq. in.	Average Si, %
E1	20 0	1460	540	1873	1020	69·6	1300	343	850	13	0·92
E2 (*a*)	18 0	1240	436	2040	890	72·0	...	...	...	...	...
E2 (*b*)	18 0	1240	578	1870	1080	87·0	1003	147	1170	12·0	0·68
E3 (*a*)	20 0	1460	570	1839	1050	71·8	...	...	...	...	...
E3 (*b*)	20 0	1460	658	1840	1210	83·0	1300	112	1112	12·7	0·88
E4 (*a*)	20 0	1460	598	1937	1160	79·3	...	...	...	...	...
E4 (*b*)	20 0	1460	597	1810	1083	74·0	...	67	1112	12·7	...
E5 (*a*)	18 3	1250	653	1695	1108	89·0	1034	222	...	13·8	...
E5 (*b*)	18 3	1250	593	1719	1020	81·5	914	...	1250	13·8	2·97
E6	16 6	1050	542	1820	985	94·0	1343	...	1033	14·7	0·40
E7	18 3	1250	648	1560	1015	81·0	950	146	1100	11·0	1·10
E8	19 0	1350	623	1600	996	73·8	1000	45	1075	11·0	0·65
E9	20 0	1460	766	1390	1068	73·0	...	...	...	...	...
E10	21 6	1650	865	1505	1303	79·0	958	88	1202	14·5	...
E11	22 9	1780	554	2345	1300	73·0	2430	179	932	...	1·03

* According to rating formula † 86% carbon

Notes: Column 3. Values taken from Fig. 2
Column 6. Values from column 4 × column 5
Column 7. Values from (column 6 ÷ column 3) × 100
Column 8. Values in round figures are approximate (probable error ± 5%)
Column 9. Dustcatcher dust only. Some values are actual reported dustcatcher figures, while others are calculated from reported figures which include washer sludge (probable error of calculated values ± 10%)
Periods covered by data are as follows: E1, year 1949 and Oct. 1950. E2, (*a*) year 1945 and Oct. 1950; (*b*) Feb. 1938. E3, (*a*) year 1949 and Oct. 1950; (*b*) May, 1946. E4, (*a*) Oct. 1950; (*b*) July, 1946. E5, (*a*) Mar., Apr., June, Nov., Dec., 1950; (*b*) Oct. 1947; E6, Oct. 1947. E7, Dec. 1945 and Apr. 1946. E8, Feb., Oct., 1946. E9, Feb., Apr., 1948. E10, Apr. 1948. E11, Sept. 1946

prevailed at the so-called Lake-ore furnaces for some 40 years, as shown by the following data for these furnaces :

Year	Furnaces	Average Blast Temperature, ° F.
1909	101	975
1912	98	967
1915	97	1024
1918	107	999
1919	109	988
1944	66	983
1950	86	975

The statement that "you can't carry high blast heats with Lake ores" has become almost a postulate. A prominent blast-furnace authority has advanced the opinion that the general inability to apply high blast temperatures economically when operating with low coke rates in the production of basic iron is probably the result of a sharp increase in basicity of the primary bosh slag, owing to the reduction of less silicon into the iron, combined with lowering of the zone of fusion and subsequent increased blast pressure and irregular stock movement. This ascription of enforced low blast temperature to low coke rate and the production of basic iron does not, however, explain the matter entirely, as the hard-hematite furnaces on basic iron, with a 1420° F. average blast temperature,

Table IV

NETHERLANDS, INDIAN, SOUTH AFRICAN, AND BRAZILIAN BLAST-FURNACE DATA

1	2	3	4	5	6	7	8	9	10	11
Furnace Code No.	Hearth Dia. Ft. In.	Potential* Coke per Day, lb. × 10^3	Pig per Day, tons	Coke † per Ton Pig, lb.	Coke per Day, lb. × 10^3	Rating, %	Slag Volume, lb./ton pig	Dust, lb./ton pig	Blast Temp., ° F.	Average Si, %
N1	15 0	900	534	2240	1085	120·5	1074	130	...	1·14
N2	15 0	900	475	2230	1060	118·0	1254	187	...	2·42
N3	15 8	970	572	1980	1130	116·5	1130	282	...	3·00
A1	16 1	1010	572	1670	955	94·5	...	...		0·70
I1	22 6	1750	1079	1615	1740	99·0	...	175	1130	...
I2	20 6	1530	995	1520	1515	99·0	...	168	1142	...
B1	25 0	2050	1110	1820	2020	98·5	...	63	...	...

* According to rating formula † 86% carbon

Notes: Column 3. Values taken from Fig. 2
Column 6. Values from column 4 × column 5
Column 7. Values from (column 6 ÷ column 3) × 100
Column 8. Values in round figures are approximate (probable error ± 5%)
Column 9. Dustcatcher dust only. Some values are actual reported dustcatcher figures, while others are calculated from reported figures which include washer sludge (probable error of calculated values ± 10%)
Periods covered by data are as follows: N1, Feb., Mar., 1951. N2, Feb., Mar., 1951. N3, Feb., Mar., 1951. A1, year 1947 (three furnaces). I1, years 1944 and 1945. I2, years 1943 and 1944. B1, July, 1950

Table V

AVERAGE UNITED STATES BLAST-FURNACE PERFORMANCE FACTORS COMPARED WITH RATING

Rating		Number of Furnaces	Coke* Rate, lb./ton pig	Dust† Rate, lb./ton pig	Sinter, lb./ton pig	Iron Output on Present‡ Lining, tons × 10^3	Slag Volume,§ lb./ton pig
Range, %	Average, %						
Under 85	81·5	10	1741	164	993	993	
85–89·9	87·3	18	1755	190	523	1104	
90–94·9	92·0	21	1715	169	550	675	950
95–99·9	96·6	28	1737	175	650	1010	
100–104·9	102·0	14	1889	184	288	848	
Over 105:							
North	109·4	7	1784	163	257	855	1000
South	117·6	8	2155	139	1014	667	2000
All Furnaces:							
North	94·0	97	1762	174	555	...	975
South	116·2	9	2167	133	1014	...	2000
All	95·7	106	1791	171	590	895	1055

* 86% carbon † Dustcatcher dust only ‡ December, 1950 § Approximate

Table VI

OPERATING DATA FOR BLAST-FURNACES OUTSIDE U.S.A., AVERAGED FOR PERIODS BETWEEN 1943 AND 1951

Location	Average Rating, %	Number of Furnaces	Coke* Rate, lb./ton pig	Dust Rate, lb./ton pig	Slag Volume lb./ton pig	Average Silicon in Pig, %
Great Britain	78·6	11	1792	150	1223	1·08
Netherlands	118·3	3	2083	200	1153	2·19
South Africa	94·5	3	1670	...	...	0·70
India	99·0	2	1520	168	1200†	...
Brazil	98·5	1	1820	63	892	...
U.S.A.	95·7	...	1791	171	1055†	...

* 86% carbon † Approximate value

Table VII

BLAST PRESSURES AND RATINGS OF UNITED STATES BLAST-FURNACES

Type of Furnace	Average Blast Pressure, lb./sq. in.		Average Rating, %	
	Northern Furnaces	Southern Furnaces	Northern Furnaces	Southern Furnaces
Small furnaces (up to 18 ft. hearth dia.)	16·0	19·8	99	106
Medium furnaces (up to 24 ft. hearth dia.)	17·8	23·6	93	118
Large furnaces (up to 28 ft. hearth dia.)	22·0	26·7	98	118

Table VIII

COMPARISON OF BLAST TEMPERATURES AND SINTER CHARGE AT NORTHERN FURNACES

Much Sinter (About 40% of Ore Burden)			Little Sinter		
Number of Furnaces	Sinter, lb./ton pig	Average Blast Temperature, °F.	Number of Furnaces	Sinter, lb./ton pig	Average Blast Temperature, °F.
7	1700	869	4	Nil	976
1	1800	894	8	10	936
4	1700	937	5	Nil	956
2	1419	913	2	Nil	1083
3	853	938	2	Nil	903
2	629	1020	1	Nil	1036
19	1425*	915*	22	4*	960*

* Weighted average

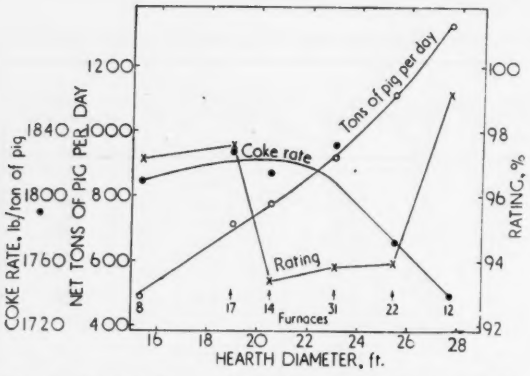

Fig. 3—United States blast-furnace performances in relation to hearth diameter

show a coke rate of 1722 lb. per ton ; considerably lower than the 1801 lb. average coke rate of the basic-iron Lake-ore furnaces with their 975° F. blast temperature. Nor, as is shown in Table VIII, does partial dilution of the Lake-ore burden by means of a substantial proportion of sinter relieve the perplexity, and as far as the present author is concerned it is still not entirely clear why the northern furnaces must accept operation at blast temperatures of less than 1000° F.

ORE

United States iron-ore requirements in 1950 were met by the production of approximately 118,000,000 tons, a rate of demand likely to continue in the foreseeable future, and which may even increase. Approximately 89,000,000 tons, or some 75%, of the ore came from the so-called 'Lake region,' an area lying generally north, with some parts south and southeast, of Lake Superior and 50–100 miles south of the Canadian border. Approximately 20,000,000 tons, or about 17%, were mined in the eastern, southeastern, and western parts of the United States, the reserves in these areas being ample to maintain pig-iron productions in the districts they serve for many years to come, even allowing for considerable expansion in local ironmaking capacity ; however, reserves in these districts are unlikely to constitute more than a small proportion of the total ore requirements of the country. The main ore deposits in eastern United States are given in Fig. 4. Some 9,000,000 tons, or approximately 8%, of the ore used during 1950 were imported, chiefly from Chile, Cuba, Spain, Sweden, Newfoundland, Africa, Mexico, and Brazil.

The Lake ores, the mainstay of United States ironmaking economy, averaged 50% Fe (natural), and probably not more than 9% SiO_2, a general grade of analysis which has characterized these ores for some decades. As with the passage of the years the prime grades of natural ore have become less plentiful but the standard of analysis in the average has been maintained by a substantial proportion of beneficiated ore, amounting to 21,600,000 tons, almost 25% of the Lake-ore production, in 1950.

During the past ten years many statements have been made to the effect that the Lake-ore deposits are nearing exhaustion. Estimates published for taxation purposes register the reserves of high-grade Lake ores as totalling 1200 million tons, of which 600 million tons can be won by high-speed low-cost open-cast mining, the other 600 million tons requiring slower and more costly underground mining. For reasons connected with taxation, however, these estimates can be regarded as conservative, and a mining consultant for one of the large American steel corporations has stated that it is certain that the amount of ore of present commercial grades not yet recovered from Lake Superior far exceeds the tonnages currently on the tax rolls.* It is true that if all the 89 million tons of ore produced annually came only from open-cast workings these reserves on the basis of the taxation estimates would be exhausted in six or seven years, thus giving some plausibility to the more sensational forecasts. Actually, however, more than 25% of the Lake-ore production is from underground mines, and the efficiency of modern earth-moving equipment is converting underground workings into open pits to a degree unthought of a few years ago. Despite such assurances the mining consultant referred to considers that it is apparent that even a total reserve of twice the tax figures, *i.e.*, 2400 million tons, is not enough to warrant complacency, but on the strength of the implications there is some reason to believe that the reserves of high-grade Lake ores can last for some 25 years at the current rate of demand ; this is not a very long span of time, but it is more than the distorted six-year estimate and it affords an interval to relieve the calls upon, and extend the life of, these reserves.

In the same region there are very large deposits of iron-bearing rock, a kind of jasper referred to by the mining technicians as taconites, containing 25–35% Fe. Some veins of these deposits are magnetic, and commercially feasible methods for concentrating these to yield a product containing 63% Fe have been established ; in 1950 some 69,500 tons of magnetic taconite concentrates were produced in fair-sized pilot plants. The mining consultant previously referred to is of the opinion that the quarryable magnetic taconite in one ore range alone represents probably 2000 million tons of 63% Fe concentrates, equivalent to 2500 million tons of the 50% Fe Lake ores, which would extend the potential life of the Lake-region reserves to 50 years.

It is well known that large reserves of high-grade ores have been proved in Venezuela and Labrador, and there are possibilities that eventual outputs of 20,000,000 tons per year can be obtained from each of these sources. If, say, 30,000,000 tons of eventual annual imports are applied to the reduction of the 90,000,000-ton annual demand for the Lake ores to 60,000,000 tons, the life of the apparent 5,000,000,000-ton equivalent reserves, in terms of natural ore and taconite concentrates, of the Lake-ore regions approaches the century mark. The iron-ore supply situation for the United States calls for energy and enterprise, but it is neither grim nor hopeless.

* D. B. Gillies, *Min. Eng.*, 1949, vol. 1, Dec., pp. 34–38.

In regard to world ore supplies, Rueckel* concurs with other competent authorities in estimating the world's actual iron-ore reserves as 35,000 million tons, which, at the present rate of consumption, might approach exhaustion in about 150 years.

Beneficiation

Analysis of the operating statistics of more than 100 United States blast-furnaces for 1950 shows that approximately 635 lb. of sinter were charged per ton of pig. On the basis of a pig-iron production of 66 million tons for the same year, the total annual consumption of sinter would thus appear to be approximately 21 million tons. From other sources the sinter-producing capacity in mid-1950 is given as about 22 million tons, which indicates that the sintering plants were operating at about 95% of capacity and signifies the importance now attached to sintering as a means of iron-ore beneficiation.

* *Blast Furn. Steel Plant*, 1951, vol. 39, Feb., pp. 195–199 ; Mar,, pp. 327–332 ; Apr., pp. 426–438.

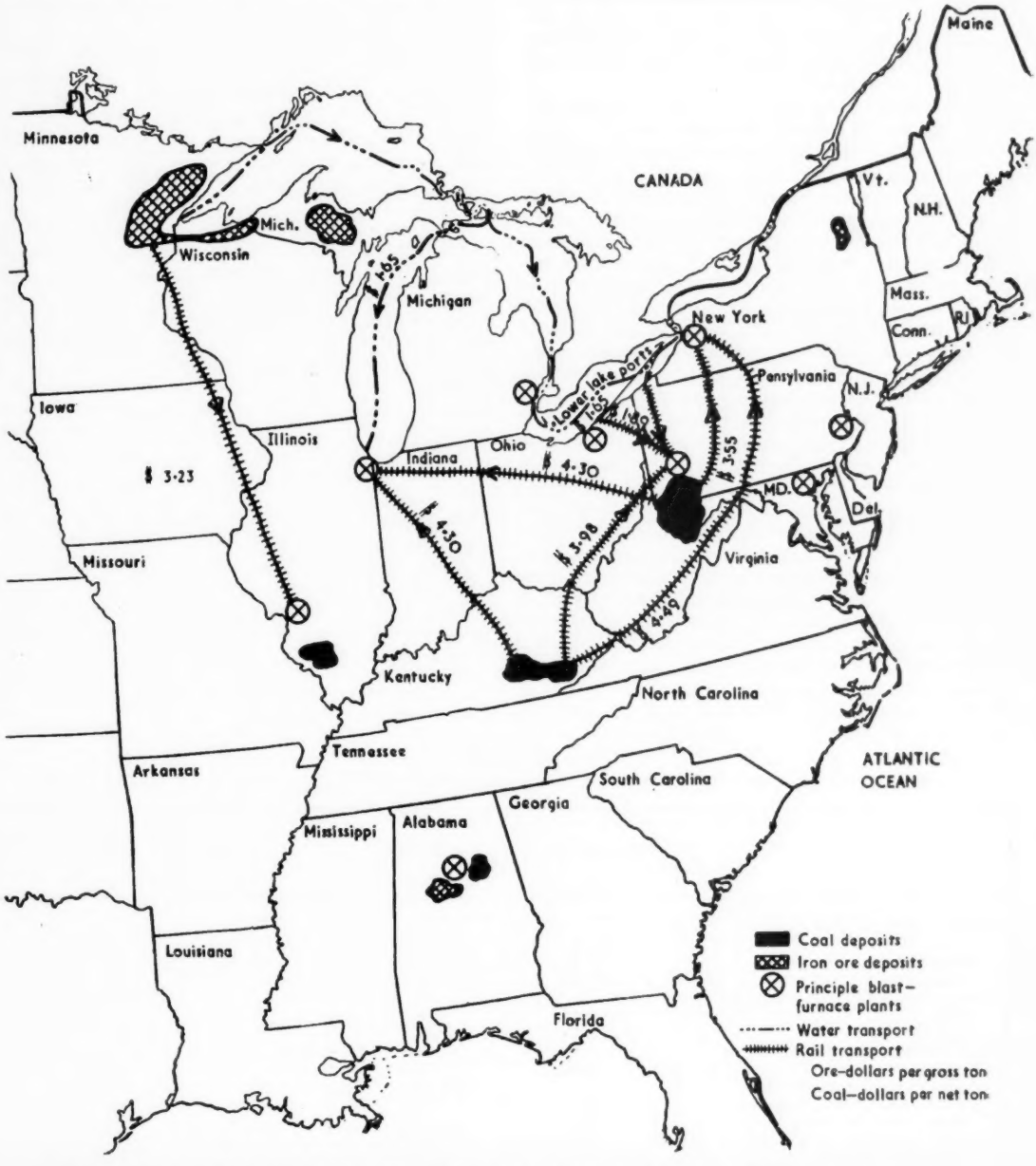

Fig. 4—Main coal and ore deposits and principal blast-furnace districts in eastern United States

Table IX

CONVERSION COSTS FOR SINTER IN 1950

Plant	Sinter Produced, tons	Type of Plant	Total Conversion Cost per Ton of Sinter	Provision for Depreciation
A	1,760,000	Pallet	$0.95	$0.07
B	710,000	Pan	$1.45	$0.17
C	50,000	Pallet	$1.65	$0.30
D	800,000	Pallet	$1.95	$0.50

Approximate conversion costs, *i.e.*, the cost excluding materials but including ignition fuel, for four sintering plants are given in Table IX.

The taconite concentrates to which reference has been made present a problem in agglomeration ; whilst the extreme fineness of this material may not preclude down-draught sintering, it does introduce a difficulty for this type of beneficiation. ' Pelletizing ' has been the subject of large-scale experiment for several years, but pellets having a sufficient degree of physical stability to withstand the necessary handling do not seem yet to have been achieved, and the process is proving a more difficult problem than was supposed.* Other schemes for the agglomeration of taconite concentrates include briquetting with Portland cement or other binder, mixing with coal or other carbonaceous caking material to form an iron-bearing coke, and nodulizing in a rotary kiln ; the last-mentioned process has been in and out of the iron-ore-agglomeration picture for many years and may once again emerge for the treatment of taconites.

Blending of ore stocks by, for instance, the Robins-Messiter system has proved useful in regions where winter conditions are not sufficiently severe to interfere with the reclamation equipment, but such mechanical blending systems have not been found at all necessary in the case of Lake ores shipped by vessel, where the routine of railroad-car sampling between mines and loading docks and the orderly spouting from the dock bunkers into the loading vessels has for many years effected a degree of blending which permits the delivery of cargo quantities on a guaranteed-analysis basis.

* *Iron Age*, 1951, vol. 167, Feb. 8, p. 106.

COAL AND COKE

Accurate assessment of the coking-coal situation in the United States is even more difficult than appraisal of iron-ore reserves. As pointed out by Averitt and Berryhill, of the United States Geological Survey,† it is impossible to define coking coal in precise terms, and it follows that assessment of the reserves is thus hardly practicable. However, Averitt and Berryhill go on to say that as low-volatile bituminous coal is a blending agent which permits the use of vastly larger reserves of high-volatile coals for coke production, the reserves of low-volatile coal are important as regards present and future supplies ; the remaining reserves of this coal are much less than 1% of the total coal deposits of the United States, of which proportion no more than half can be regarded as recoverable.

If the figure of 1,213,000 million tons be taken as representing the estimated coal reserves of the United States, the foregoing observations lead to the conclusion that there remain some 6000 million net tons of recoverable low-volatile coking coal. About 20 million tons of this coal are used annually in the production of coke, but approximately 60 million additional tons are consumed as a desirable semi-smokeless fuel. This total annual consumption of 80 million tons would probably exhaust the known reserves of this mainstay of the coking industry in 75 years, but if the applications, other than coking, were cut in half, *i.e.*, to 30 million tons per year, the 6000 million reserve tons would seem good for 120 years. In the meantime the ironmaking industry has at least the good intention of striving to do the best with what it has.

There is little question that the washing of coking coal benefits blast-furnace operation, and, with the disappearance of the choicest low-ash coals, coal

† *United States Department of the Interior* 1950, Geological Circular No. 94.

Table X

COMPARATIVE EFFECT ON FURNACE PERFORMANCE OF COKE FROM UNWASHED COAL

	Unwashed Coal	Washed Coal	Effect	
			Amount	%
Coke Analysis (dry):				...
Ash, %	11·9	10·4	−1·5	...
Sulphur, %	0·98	0·88	−0·10	...
Fixed carbon, %	87·8	89·3	+1·5	...
Daily Analysis Variations:				
Ash, max., %	14·1	11·0	...	...
Ash, min., %	11·1	10·1	...	...
Sulphur, max., %	1·08	0·97	...	...
Sulphur, min., %	0·82	0·80	...	...
Furnace Performance:				
Iron production, tons/day	781	844	+ 63	+ 8·1
Coke rate, lb./ton pig	1909	1760	−149	− 7·8
Slag volume, lb./ton pig	1286	1091	−195	−15·2
Casts over 0·40% S	6·1	3·8	−2·3	...

washing assumed an obvious position as an indispensable expedient, although it required authoritative voices for the industry to proceed from an acknowledgment of the principle to action based on the practical application of it. One of these voices was that of King, who in 1943 presented an actual case history of the manner in which the blast-furnace responds to coke produced from washed coal.* A summary of King's data is presented in Table X, and the impact of like presentations has been such that in late 1950, despite six years of obviously declining quality of raw coking coals, a large group of blast-furnaces received coke containing an average of 85·1% carbon, 9·8% ash, and 0·9% sulphur, as compared with the 1944 figures of 84·5% carbon, 10·5% ash, and 1·02% sulphur. In 1944, 30% of the coking coal for these furnaces was washed, and in 1950, 60% was washed.

At most United States plants the coke arrives above the blast-furnace bunkers by means of hopper-bottom railway cars, but at quite a few furnaces, particularly the newer units, the coke is brought to the furnace high-line by belt conveyor. There are two schools of thought on whether from this point the coke should be distributed to the furnace bunkers by belt or by self-propelled transfer cars, but it is perhaps possible to say that the belt conveyor is preferred when there are, or are to be, perhaps not more than four furnaces in line, while transfer-car provision is made for a more extended line of furnaces.

Almost all the coke is screened at some point between the coke wharf and the furnace skip, the ideal arrangement being a double screening at the coke plant, producing nut coke below about $1\frac{1}{4}$ in. and breeze below about $\frac{5}{8}$ in. ; the nut coke is charged to the furnace separately. At most furnaces the desirable final coke screening is just before the furnace skip is carried out, the final basis of separation usually selected being about $\frac{3}{4}$ in., which assures a reasonable degree of breeze removal even at the expense of screening-out some nut-coke.

The main coke deposits and principal blast-furnace districts in eastern United States are included in Fig. 4.

* *Met. Tech.*, 1943, Sept., *Tech. Publ. No.* 1618.

REFRACTORIES

The impression that United States blast-furnaces in general are, and have for a long time been, favoured with a particularly competent quality of refractories, is strong and persistent. Analysis of iron production on the existing linings of over 100 United States furnaces (*see* Table V) gives an average figure of almost 900,000 tons and, as there is no more reason to believe that the average current lining is now any nearer the end of its campaign than it was at the beginning, expectancy of a production of some $1\frac{3}{4}$ million tons of iron for the average lining cannot be considered over-optimistic. As the average daily production appears to be in the region of 950 tons, the approximate expectancy of the life of the average United States blast-furnace lining thus appears to be 1830 days, or some five years. Although this immediate situation undoubtedly reflects the results of improvements in brickmaking techniques in recent years, such as, for instance, the greater resistance to carbon deposition, disintegration, and abrasion, the figure is also a component of the misadventures in installation, occasional sub-quality in manufacture, and the possible subjection of linings to extreme and abnormal operational abuse.

General fundamental characteristics of various types of ceramic refractories employed in United States blast-furnace linings are shown in Table XI. 'First Quality' firebricks, the clays for which originate almost entirely from Pennsylvania and Kentucky, have been the predominant lining material for many years and have the usual intentional variations in accordance with the respective positions (*i.e.*, hearth, bosh, inwall, and top) for which they are intended. Typical modern manufacture is by the power press or semi-dry process, with de-airing to encourage imperviousness to gas penetration, and it is customary to establish a reducing atmosphere in the kiln towards the end of the burn to convert ferric iron to a more or less ferrous condition, in which it is less active in the catalytic promotion of carbon deposition. Hard-burn, or Cone 18 bricks have been used in blast-furnace linings since 1935, and by 1943 one manufacturer alone had furnished these special bricks for parts of the linings of ten blast-

Table XI

GENERAL CHARACTERISTICS OF BLAST-FURNACE REFRACTORIES

	First Quality	Hard-Burn (Cone 18)	Extra-Hard-Burn (Cone 23)	Super-Duty	Semi-Silica
Burn, in cones	15–16	18	23	...	...
SiO_2, %	51–53	51	53	51	78
Al_2O_3, %	40–39	40	42	42	18
Weight, lb./cu. ft.	130–137	138	144	...	113
Porosity, %	17	15	14	14	28
P.C.E. Fusion	$32\frac{1}{2}$	$32\frac{1}{2}$	34	34	29
Deformation at 25 lb./sq. in. load					
at 2460° F.	1·1%	0·8%	0·1%	...	1·0%
at 2640° F.	5·4%	3·0%	1·2%	4%	6·5%
Reheat Behaviour, linear change, %					
at 2530° F.	0·0	0·0	0	...	+0·2%
at 2730° F.	+0·5	+0·5	0	+0·1	−1·2%
at 2910° F.	+1·0	+1·0	−0·5	...	...

furnaces ; by the end of 1950 the same manufacturer had supplied Cone 18 linings, complete or in part, for more than 70 furnaces. Among the advantages of the hard-burn is the conversion of the iron in the clay to iron silicate, in which form it is definitely prevented from catalytically promoting the destructive deposition of carbon. One disadvantage of the hard-burn bricks is the considerable difficulty experienced in cutting, and in some cases 'First Quality' bricks are used against the shell where some cutting may be required, despite the considerably higher cost involved. Cone 18 bricks may soon be used in stoves.

Going even beyond the hard-burned Cone 18 refractories, manufacturers in the U.S.A. have introduced the extra-hard-burn Cone 23 fireclay bricks, which are burned to a still higher temperature, this being possible because of the high purity and high refractoriness of the chosen clays. The high density of this type of brick, in conjunction with a burn not used elsewhere in the world, gives a resistance to deterioration under blast-furnace conditions which will probably lead to new lining records. One manufacturer has supplied this grade of refractory for twelve furnaces.

'Super Duty' firebrick is principally used in the hotter parts of blast-furnace stoves, *i.e.*, the combustion-chamber skin-wall, the dome, and the topmost checkers ; it has shown good resistance to alkali penetration, which for a time was seriously affecting stoves fired with fine-cleaned gas, a situation particularly marked previous to the wide adoption of flame-temperature control on stove burners. Attention should be drawn to a possible source of confusion regarding the nomenclature of some of these refractories, in that some brick manufacturers refer to Cone 23 (extra-hard-burn) brick as 'Super Duty.'

'Semi-silica' brick—a material of somewhat lower silica content than is understood by the term in Britain—has found considerable recent application in the hotter parts of stoves, replacing to some extent the Super Duty brick previously described. There has been some use of semi-silica brick in the top furnace lining, where, in association with the wearing plates, it has shown, particularly in a spiegeleisen furnace, superiority to all other varieties of bricks in resisting physical and chemical degeneration.

In regard to the previously mentioned impression with reference to the peculiarly high quality of United States blast-furnace refractories, attention is called to the bottom lines of Table XI. The heat test of the American Society for Testing Materials shows that United States blast-furnace brick is slightly, but prevailingly, after-expanding, *i.e.*, upon exposure to high temperature in use the bricks acquire a permanent increase in linear dimensions, which makes for a firm and compact masonry structure whereas the contrary characteristic of after-contraction encourages looseness of the brickwork. It is the present author's opinion that it is to this characteristic of after-expansion, which is perhaps not over widely emphasized, as much as to any other factor, that the competence of United States refractories can be ascribed ; it is a characteristic not met with in ceramic blast-furnace refractories in many other parts of the world, a situation which may have originated or encouraged the development of carbon as a blast-furnace refractory material.

Carbon Refractories

Although Britain was perhaps not the birthplace of carbon as a blast-furnace lining material it has surely been the vigorous nursery for the measure, as has been competently and authoritatively shown by Elliot.* The position in the United States was presented in late 1950 by Ess,† and was brought up to date by Kraner and Baab.‡ For the purposes of the present review it will be sufficient to quote a few statistical data on the subject, and briefly to discuss certain relevant aspects.

By the end of 1950 carbon hearth linings had been installed in 86 United States blast-furnaces, of which 14 had a carbon bottom pad only and 51 had double carbon walls in addition ; the remaining 21 furnaces had single carbon walls. The annual position in regard to carbon installations since 1945 has been given by Kraner and Baab as follows :

Year	Installations
1945	5
1946	10
1947	16
1948	35
1949	13
1950	7

At first glance it might appear from the foregoing data that carbon is losing favour, but this is not the case, as the 1951 trend is certainly in an upward direction. The explanation is approximately as follows.

In 1936, the present author and others reported on carbon hearth installations (both of the monolithic and machined-block types) in England, and of the ensuing decrease in hearth breakouts. Impressive accounts of carbon hearth performances in Germany were also given by a representative of a large carbon-manufacturing concern in the United States, and by 1946 fifteen carbon hearths had been installed. Despite the increase of carbon installations to 35 in 1948, there were some conservative operators who relied upon the high quality of United States blast-furnace brick, but even some of these followed the trend towards carbon refractories. The reaction was bound to come : the engineering concepts of what constitutes a proper carbon installation were varied and not all of them were soundly based, and the possibly devastating effects of leaking coolers and the infiltration of air during back-draughting were overlooked or ignored. There were some failures—not many, but occasionally of the spectacular kind—and many interim inspections disclosed soft spots, intrusions of iron fins, or floating blocks. The trend was reversed, and in 1950 only seven new carbon hearths were installed.

Later, when sober inventory was taken, it was found that the great majority of carbon users had experienced no trouble and were satisfied with the

* G. D. Elliot, *Iron Age*, 1950, vol. 166, Sept. 21, pp. 88–91.

† T. J. Ess, *Iron Steel Eng.*, 1950, vol. 27, pp. 68–75.

‡ Paper read before the American Institute of Mining Engineers, Division of Metals, Cleveland, Ohio, April, 1951.

material. The average production on existing carbon hearths appears to be more than 840,000 tons, which, considering that many of the carbon hearths have been in operation for less than 600 days, bears comparison with the approximate figures of 900,000 tons and 900 days previously obtained for all current United States blast-furnace linings. Attention is being paid to the opinions of, for instance, Elliot of Great Britain and Kraner and Nolan of the U.S.A., and it can be safely said that 1951 will see the reinstatement of carbon as an accepted blast-furnace lining material. Serious consideration is even being given to all-carbon linings, as advocated by Elliot, and it is interesting to speculate that if a carbon-lined bosh and lower inwall would promote smoother stock descent and thereby permit increase of the acceptable blast temperature at the northern United States furnaces from the present average of 975° F. to, say, 1175°, the resulting coke economy might be worth $200,000 per furnace per year, in addition to the increased iron production if the rating in terms of total daily coke consumption were maintained.

HIGH-TOP-PRESSURE OPERATION

The initial development and subsequent demonstration of high top pressure have been carried out almost exclusively by the Republic Steel Corporation, who have been liberal in the dissemination of information, and many visits have been made to the plants concerned. After careful consideration other companies are now preparing units for high-top-pressure working, and several of the new furnaces now in course of construction will be equipped to operate on this basis if desired. Although the Republic Steel Corporation has converted six furnaces for elevated-pressure operation since 1944, there has been no general headlong move in this direction comparable with that towards carbon hearths, of which almost 90 had been installed in the same period. And yet high-top-pressure operation cannot be considered more of a speculation than the adoption of carbon refractories, as a blast-furnace is necessarily saddled with its refractories, good or bad, once they are installed, whereas if high-top-pressure working should prove unsuitable in any particular case, reversion to orthodox working is simple. However, performances with elevated pressure have commanded general interest and attention, and few operators would question the proposition that no new furnace should be built without provision for high-top-pressure operation. By the end of 1951, or shortly after, at least 13 furnaces in the U.S.A. will be so equipped.

The reason for the so far relatively cautious approach to elevated-pressure working undoubtedly lies in the rather pronounced interruptions which marked the early years of the innovation, owing simply to the fact that the engineering problems involved could not be anticipated with accuracy. A certain amount of trial and error was inevitable, and the cutting of bells, blowing of washer seals, troubles with bleeders, and excessive tuyere losses went a long way towards mitigating the promise of higher production and lower coke consumption. It should also be borne in mind that whilst potential advantages of high-top-pressure working are such as greatly to appeal to managements, the disadvantages are more pronounced the nearer one approaches the actual operational side of pig-iron production, and as, naturally, it is the operators' opinion which managements seek on the question of whether or not high-top-pressure operation is to be adopted it is little wonder that the general approach has been conservative in nature.

An account of performances of high-top-pressure furnaces during 1950 has been given by Liggett,* who gives the assurance that operational interruptions are being lessened. For instance, at a particular high-top-pressure furnace, in 1948 the lost time above that experienced with normal operation was 65%, which decreased to 40% in 1949 and showed a further trend downwards in 1950. Another furnace showed 53% increase in lost time during its first year of elevated-pressure operation, but the figure in 1950 was only 11% above normal, while at a third furnace, now in its second year of high-top-pressure operation, the time loss is only 18% greater than normal. All in all, Liggett believes that the lost time with elevated-pressure working may be 10–20% greater than that with normal pressure, and he goes on to minimize the factor of bell-cutting, one of the grave liabilities of the system : equalization of the pressure above and below the large bell—a prerequisite of high-top-pressure operation since its inception—has now been arranged to exist at all times except during the lowering of the small bell, when the space between the bells is brought to atmospheric pressure by the opening of a relief valve, thus markedly reducing the time of exposure of the large-bell seating to high-pressure differential, and consequently greatly minimizing the liability of the contact seat to cutting influences. Indeed, Liggett finds that the arduous hard-facing of bell and hopper surfaces is no longer necessary, and that bell erosion has ceased to be a problem.

* *Yearbook of the Amer. Iron Steel Inst.*, 1950.

Table XII

DATA FOR 22-FT. HEARTH FURNACE ON NORMAL AND ELEVATED TOP PRESSURES

	Production, tons/day	Coke Rate, lb./ton pig	Dust Rate, lb./ton pig	Top Pressure, lb./sq. in.	Rating, %
Normal operation (1 year)	899	1661	127	1·34	87·5
Pressure operation (1 year)	969	1597	62	7·0	90·0
Change	+70	−64	−65	...	...
	(+7·8%)	(−3·9%)	(−51%)	...	...

Table XIII

DATA FOR LARGE FURNACE ON NORMAL AND ELEVATED TOP PRESSURES

	Production, tons/day	Coke Rate, lb./ton pig	Dust Rate, lb./ton pig*	Top Pressure, lb./sq. in.	Rating, %
Normal operation	1396	1680	182	1·5	97·5
Pressure operation, Oct., 1950	1420	1680	117	5·0	99·5
Change from normal	+24	...	−65	...	...
	(+1·7%)	...	(−36%)	...	...
Pressure operation, Mar., 1951	1398	1678	170	3·0	97·5
Change from normal	...	...	−12	...	...
	...	...	(−7%)	...	...

* Includes washer sludge

Liggett's data regarding the performance of a 22-ft. hearth furnace for a year's normal operation and for an ensuing year on elevated pressure are condensed in Table XII; it will be seen that there was a reduction in the dust make, this being one of the anticipated advantages of high-top-pressure working. At another furnace, with a 25½-ft. hearth, the average daily iron production during a two-years run on normal top pressure was 1067 tons, whilst the average production per day for the three ensuing years, when the top pressure averaged 10 lb./sq. in., was 1106 tons, an increase of 4·3%; for the final year (1950), the increase amounted to 5·5%. In addition to the achievement of higher pig-iron production and lower dust rates, there seems to be an intangible advantage of smoother furnace working, although, in general, according to Liggett, coke rates have not been reduced, and when the blowing rate is increased in view of the lower dust figures, coke consumption is inclined to suffer.

Typical data for a large furnace which has been operating on high top pressure at another plant during intermittent periods in the past year are given in Table XIII, and indicate that in this particular case the operators seem to be content with the benefits, chiefly a reduction in the dust rate, obtained with a rather modest top pressure.

A report from a multi-furnace plant where the blast-furnace-gas distribution conditions call for an initial pressure of over 100 in. W.G. is of interest. In this case there are no booster fans, and the top pressure required (3–4 lb./sq. in.) is necessarily provided by the furnaces, thus leading to a coincidental 'high-top-pressure' operation. The flue-dust figures for these furnaces are said to be exceptionally low.

Briefly, the current position of elevated-pressure working is probably that many operators favour a moderate top pressure, *i.e.*, a few pounds above normal, it being the belief that most of the liabilities of the system are thus avoided and that sufficient benefits are obtained to justify the added expenses. Also, in building a new furnace there is a fairly widespread feeling that it is preferable to incur the relatively small additional cost of equipping the unit for high-top-pressure operation rather than that the furnace might be found lacking if some outstanding advantages emerge for the elevated-pressure system.

EXPERIMENTS WITH OXYGEN

In recent years there have been reports of blast-furnace operation in certain parts of Europe with blast containing up to 50% of total oxygen. Although, so far as the United States furnaceman was concerned, such reports were beguiling rather than convincing they stimulated considerable interest, and in 1948 three large industrial concerns in the U.S.A. pooled sufficient resources to conduct an extended oxygen-enrichment trial on a medium-sized blast-furnace. The raw materials charged were typical of Lake-ore practice for the production of basic iron, and the furnace was operated for alternating periods during 1949 on normal blast and on blast enriched to the extent of an oxygen increase of 3 or 4%, which was considered at least sufficient to indicate trends, and this proved to be the case. The effects of the oxygen-enriched blast were in certain respects strikingly similar to the effects of high-temperature blast, which Lake-ore furnaces find difficulty in accepting. The furnace at which the trials were conducted normally found a blast temperature of about 925° F. quite warm enough, and the reaction to the oxygen-enriched blast was similar to that which would have probably taken place with a rise of 200–300° F. in blast temperature.

The deduction followed that furnace practices where high-temperature blast is regularly accepted might more readily benefit from oxygen enrichment. High-temperature blast is, of course, ordinarily obtained far more cheaply than high-oxygen blast, but there are some practices in which the blast temperatures readily acceptable are such as to approach, or even reach, the ultimate capabilities of the stoves to generate or the equipment to handle safely, and in such cases oxygen-enriched blast might show favourably. Ferromanganese blast-furnace practice is in this category, and throughout the year 1950 it was to a ferromanganese furnace that the research was directed. Specific data are not yet ready for publication, but it can be said that the results were encouraging as regards production, fuel rate, and furnace performance; also, manganese losses—an important factor in ferromanganese practice—did not alter to a disquieting degree. The investigations were discontinued at the beginning of 1951 for reasons entirely unconnected with oxygen-enriched-blast working.

DESIGN, CONSTRUCTION, AND EQUIPMENT

Where new blast-furnaces are erected at an existing plant it is almost inevitable that the layouts conform to the established arrangements, which may be the 'in line' type shown in Fig. 5, or the echelon or

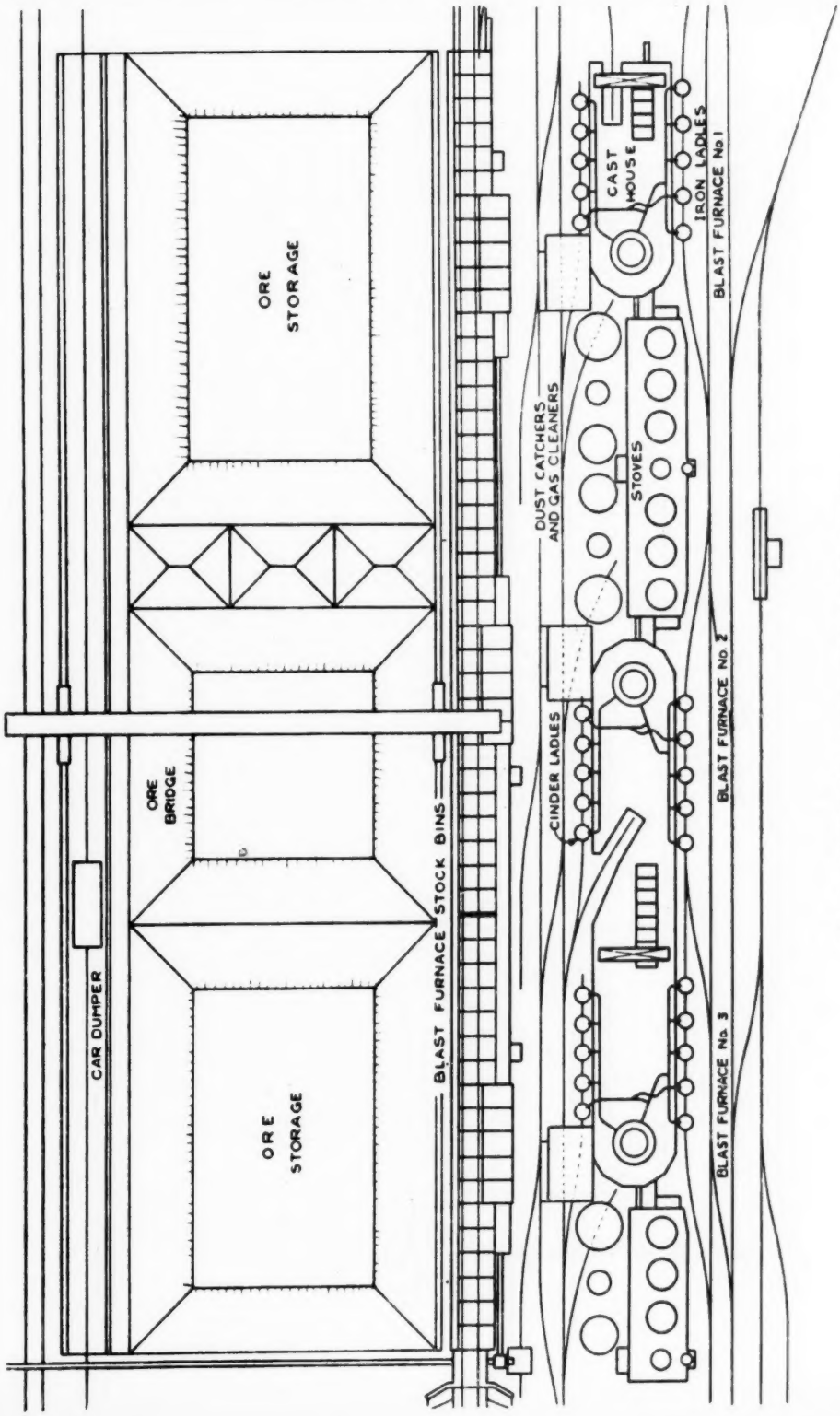

Fig. 5—Straight-line arrangement of blast-furnaces

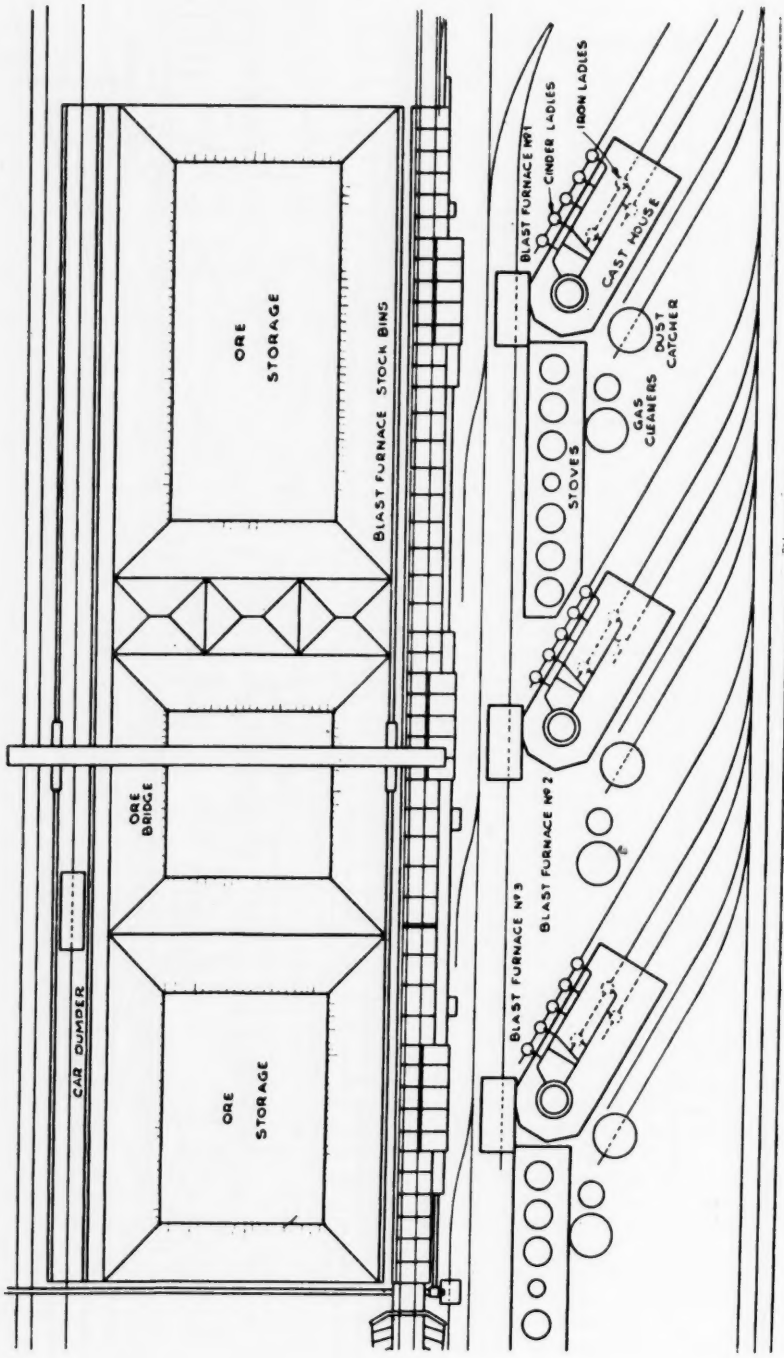

Fig. 6—Echelon arrangement of blast-furnaces

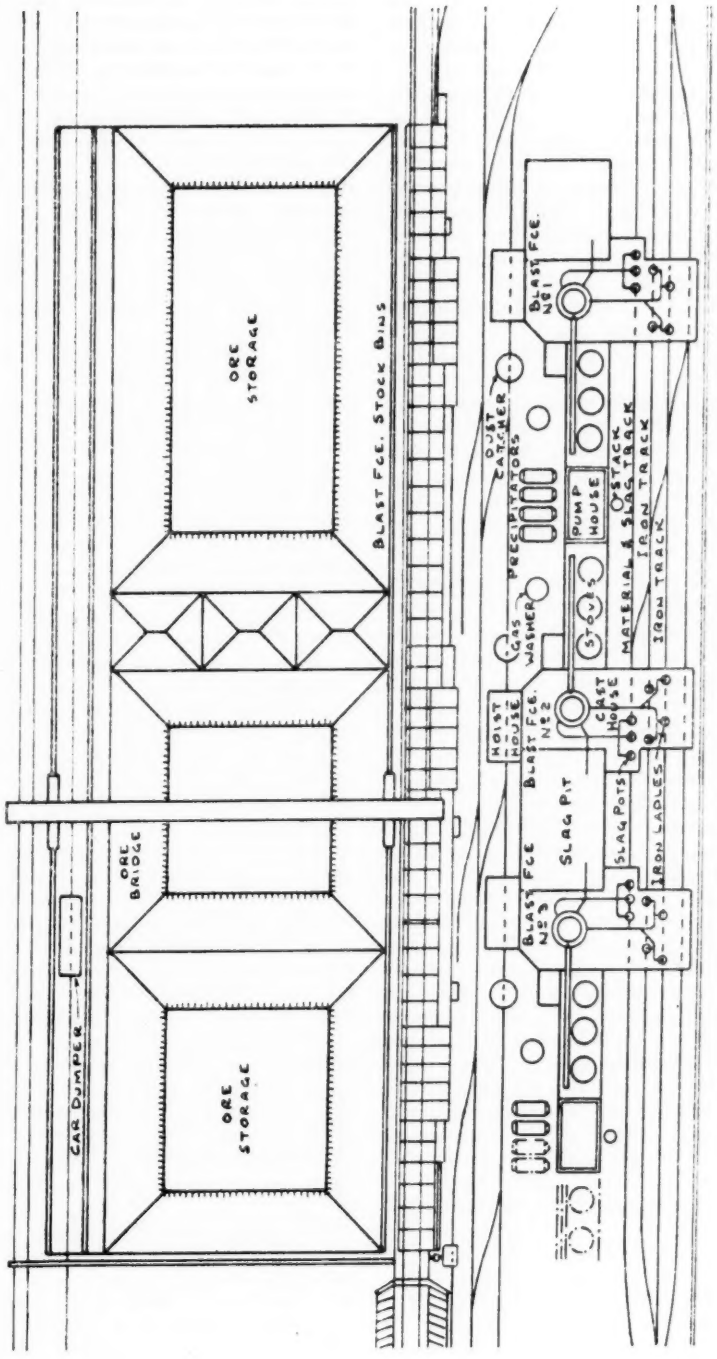

Fig. 7—Crosswise cast-house arrangement

Gary type, illustrated in Fig. 6. In both cases the hot-metal and slag tracks run parallel with the cast-house.

In the case of furnaces erected on a new site, and particularly where there is no necessity to connect intimately with existing railway lines, attention in the United States is being given to what may be termed the crosswise cast-house layout, illustrated in Fig. 7. This is an arrangement similar to that employed in Great Britain on certain new furnaces and consists of the hot-metal and slags extending crosswise of the cast-house, giving the advantages of through rail lines, relief from traffic congestion, compact cast-house, economy in plant dimension, and relative ease of working with large-capacity hot-metal and slag ladles. The 'open' foundation with the floor immediately around the furnace and the extended cast-house carried on columns on beams, towards which there is a trend in the United States, is essential to the crosswise cast-house layout.

It is becoming increasingly common practice to place the stoves on yard-level foundations, with an elevated operating platform at approximately cast-house level, giving ease of movement between the stove battery and the furnace, both at bottom and top (the top platforms of stoves and furnace are approximately the same height above the yard with this arrangement). Perhaps the only disadvantage is that the full stove combustion-chamber height cannot be utilized, and greater cross-sectional area of the combustion chamber, possibly necessitating larger stove diameter, may be required if adequate gas-burning capacity is to be attained.

Cast-iron furnace columns are now seldom found in new erections, where heavy rolled-steel sections augmented with 2-in. thick flange plates have become customary. Mantles and shells are welded.

It is fitting that attention should be drawn to the vital contributions which many items of ancillary equipment of proprietary design have made to the blast-furnace art. More than 130 blast-furnaces in the U.S.A. are equipped with automatic charging control ; there are more than 50 modern air-cylinder bell hoists and 30 dual-motor skip hoists ; almost every furnace has an automatic stockline recorder, and many have two ; at least 160 of the probable 800 hot-blast stoves in the United States are equipped with suspended-element chimney valves, 280 are fitted with gate-type hot-blast valves, and 320 have modern large-capacity automatically regulated pressure burners largely equipped with automatic excess-air provision responsive to top-checker temperatures. The last-named item has been a real boon in the preservation of brickwork against the effects of alkali penetration.

Most of the dual-motor hoists at the smaller or medium-size furnaces employ a combination of series-parallel and motor-field control, and at the majority of the large new furnaces a combination of adjustable voltage and motor-field control arranged to provide for series-parallel operation in the event of the motor-generator set becoming inoperative is used. Of the 16 new or recently rebuilt furnaces, all but one have pneumatic bell hoists.

Modern stoves are represented by the Freyn, McKee, and Mohr types, all of which employ cluster tiles with 2-in. openings. Elliptical combustion chambers are almost generally superseding the circular type. At all the new furnaces, and at many of the older ones, there are three stoves, and there has been a realization of the need for combustion chambers of ample horizontal area, in many cases exceeding 50 sq. ft. This provides sufficient gas-burning capacity to maintain a reasonable blast temperature, characteristically about 1100° F., even if one of the three stoves is out of service. The use of large combustion chambers is probably also to some extent a recognition of the restriction in gas-consuming capacity imposed by placing the burners on an operating platform part way up the combustion-chamber height in accordance with furnace-plant layout trends, as previously mentioned.

The so-called Lake-ore furnaces with their 975° F. average blast temperature are not particularly good proving grounds for stove capacity, and on the other hand such hot-blast practice presents an opportunity for severe abuse of stoves by overheating, owing to firing the stoves as though a call for 1500° F. blast were imminent and continuing such firing of the on-gas stoves during the blast periods of the on-blast unit. Fortunately, in most cases, although not in all, this contingency is forestalled by attention to stack-gas-temperature measurement and the enforcement of a schedule of 'bottling-up' the hot stove when a predetermined stack-gas temperature has been reached.

At the furnace top, equalizer and relief control equipment is coming more and more into use. This is the facility that equalizes the pressure in the main hopper and that of the top gas, just before the bell is lowered ; it is indispensable in high-top-pressure practice, although there are almost twice as many such installations in normal-top-pressure furnaces. The system is of great value in prevention of hesitation or failure of the bell in opening and also in avoiding up-rush of gas into the hopper, which is so disturbing to the orderly movement of stock from the bell and therefore disruptive of good distribution.

It is usual United States practice to provide a primary gas washer for each furnace and to have two furnaces sharing secondary gas-cleaning facilities. Fine, or secondary, cleaning equipment consists either of Cottrell tubular or Koppers plate-type electrical precipitators, or Freyn rotary disintegrators, the last-mentioned being the system successfully applied in the fine cleaning of ferromanganese-furnace gas. Final cleaning is frequently directed to a dust content of less than 0·01 grains per cubic foot, especially where coke-oven underfiring with blast-furnace gas is involved.

The United States furnaceman is very receptive to modern labour-saving and accuracy-promoting equipment, but in two regards he seems to be lagging ; he has been slow to adopt mechanical bin gates and he still appears content to struggle with the massive, cumbersome, insecure, and dangerous stove gas-port door. One looks to Britain for enlightenment in regard to the closed-cab scale car equipped with bin-gate-operating mechanism, and to indicate the many excellent installations of gate-type gas-port valves.

MANNING THE FURNACE

The changes which have taken place in the manning of United States blast-furnaces during the past 14 years are of interest. At a typical multi-furnace plant in 1936 the total labour force on three shifts, excluding maintenance crew, totalled 233 men, and in 1950, for the same number of furnaces, the comparable total was 335. A condensation of the 24-hr. labour-force reports for these two widely separated periods is as follows :

	1936	1950
Superintendents and General Foremen	5	10
Metallurgical Assistants	1	2
Clerks and stenographers	3	6
Safety Supervisor	...	1
Janitors	1	7
Stock-House Foremen	3	3
Stock-House Leaders	...	3
Scale-car operators	21	21
Bin men	21	21
Breeze men	8	16
Materials unloaders	11	22
Furnace Foremen	6	9
Cast-house men	95	90
Hot-blast Foremen	...	3
Hot-blast men	21	21
Sample carriers	1	3
Gas-washer men	5	22
Cranemen	...	4
Casting-machine men	11	28
Ladle-house men	10	18
General labour	10	25
Totals	233	335
Average tons pig per day	4200	5707
Tons pig per pay-roll man	18·0	17·1

The comparative figures reflect to some degree the pressure of labour unionization, but they also demonstrate the enlightened demand for better supervision, better knowledge of what is going on, better record-keeping, better housekeeping, and reduction of wind-off time owing to inadequate hands and exhausted arms. At this plant it is no longer considered smart, heroic, safe, or profitable for any man to put in a double turn of duty.

In 1950 the average wage of blast-furnace workers in five plants involving 28 furnaces was $1·63 per hour.

PIG-IRON PRODUCTION COSTS

In many cases there is little variation between widely separated United States blast-furnace plants in regard to the total cost of materials charged per ton of pig. This is merely a reflection of the fact that the furnaces are usually located either within reasonable reach of the coal or within reasonable reach of the ore. For instance, in 1950 a blast-furnace plant on Lake Erie, receiving water-borne ore but rather long rail-haul coal, incurred a total-materials cost of $27.50 per ton of pig, the cost of ore and coke, respectively, per ton, being $7.25 and $14.40. A plant near Pittsburgh, close to the coal mines but 150 miles by rail from Lake Erie ore ports, paid $9.10 per ton for its ore and $11.60 per ton for its coke, the total-materials cost per ton of pig being $27.50, only 10 cents different from the lake-side plant. In 1950 the average total-materials cost at five typical plants representative of different locations was $28.04 per ton of pig.

Of course there are plants not situated advantageously for either ore or coke, at which a ton of ore may cost $10.00 and a ton of coke $20.00, but such plants are in operation today because of the heavy demand for pig iron and its price of $50.00 per ton, and in less favourable circumstances the economics of such plants would be precarious.

Cost above materials is naturally influenced by the magnitude of the pig-iron production, as is shown in Table XIV : the figure of $4.70 there given for the average gross cost above materials per ton of pig can be considered as being made up as follows :

Labour (including repair labour)	$1.00
Repair materials	$0.25
General expense	$3.45
Total	$4.70

Some of the principal items of 'general expense' per ton of pig are :

Steam and blowing	$1.21
Relining fund	$0.33
Transportation and handling materials	$0.82
Electric power	$0.07
Casting machine and ladle house	$0.36
	$2.79

The degree to which maximum theoretical gas credits (the monetary receipts if all the blast-furnace

Table XIV

COST ABOVE MATERIALS AT VARIOUS PLANTS, 1950

Number of Furnaces	Total Iron Production in 1950, tons	Cost Above Materials Per Ton Pig, $		
		Gross	Gas Credits	Net
3	711,200	5.86	2.67	3.19
3	732,900	5.06	1.97	3.09
4	905,000	4.64	1.67	2.97
6	2,201,000	4.60	1.95	2.65
7	1,940,000	4.33	1.98	2.35
8	3,129,000	3.65	2.21	1.41
Average (direct)		4.70	2.08	2.62

Table XV

BLAST-FURNACE GAS CREDITS

Plant	Maximum Theoretical Credit Per Ton Pig, $	Actual Credit	
		Per Ton Pig, $	Percentage of Theoretical
1	2.65	1.98	75
2	2.44	1.97	80
3	2.53	1.95	77
4	2.68	2.21	83
5	1.92	1.67	86
6	2.11	1.74	83
7	2.49	2.06	83
Average	2.40	1.94	81

gas other than that used in the stoves were sold to the best-paying consumer) are approached in practice is of interest, and the average gas-credit positions at seven typical United States plants are shown in Table XV. A typical market price of blast-furnace gas in United States steelworks, calculated according to the replacement value of otherwise-purchased fuels, is about $0.32 per million B.Th.U., and the average gas credit is about 6% of the total gross pig-iron cost.

Some 25 years ago the theoretical maximum gas credit was about $1.25 and the actual credit approximately $0.80 (65% of possible), per ton pig, equivalent to 4% of the total gross pig-iron cost; the typical market price, based almost exclusively on replacement of boiler coal, was about $0.15 per million B.Th.U. Since then improvement in gas cleaning has been the principal step in the advances which have been made in realizing blast-furnace-gas values. Today much of the gas is credited on the basis of replacing fuel oil at a rate of possibly $0.45 per million B.Th.U., a market to which the key to admission has been the degree of gas cleanliness involving a dust content of not more than 0·01 grains per cubic foot.

Historical Note No. 27

The First English Blast-Furnace

By Dr. H. R. Schubert

It is generally assumed that the charcoal blast-furnace was introduced into England by French founders coming from Normandy and Picardy in Northern France, between 1490 and 1500.[1]

The term "*iron founders*" first occurred in 1490, the place of their activities being Buxted, in Sussex, on the southern fringe of the ancient Forest of Ashdown.[2] There is, however, nothing that allows any definite conclusion about the nature of their work apart from the term "*founders*." This might signify a blast-furnace although there is no indication of such a one worked at Buxted before 1543,[3] which is half a century later. On the other hand, it is quite possible that the activities of these founders were concerned with casting shot (bullets). In this, any kind of iron, even such as was produced in a bloomsmithy, could be employed by remelting it in a small moveable hearth with the addition of various fluxes, such as antimony or tin, to facilitate liquation.[4] The very brief reference to iron-founding at Buxted is much too vague to assume that a blast-furnace was in existence in this country in 1490. The first definite evidence is about six years later.

In 1496, King Henry VII prepared to secure the northern border of England against a Scottish invasion.[5] On 13th December, he commissioned one Henry Fyner to engage as many artificers, termed "*founders*," and labourers as were wanted for the erection of buildings necessary for the manufacture of iron, which was intended to be used by the Royal artillery in the war with Scotland.[6] Nine days later, on 22nd, advance payments began to be made to the same Henry Fyner, who was a goldsmith of Southwark (London), for "*wrought iron*," and on 17th March 1497 for "*rough iron*."[7] Both were produced at Newbridge in the Forest of Ashdown, which belonged to the Crown. The wrought or bar iron was forged by the "*great water hamor*" and was worked into various appliances for binding wheels and stocks of gun-carriages. These were strakes, *i.e.*, sections of wheel-rims, duledges, *i.e.*, dowels or pegs for connecting the felloes of the wheels, and duledge-nails, bars for axle-trees, bolts with forelocks, *i.e.*, with wedges to keep the bolts in their places, cross-bars, and bolsters, *i.e.*, transverse bars over the axles of the carriages. All this bar iron was worked for the King at Newbridge at a price of £4 6*s*. 8*d*. per ton, and was then carried at the King's expense to the Tower of London.[8] The raw or pig iron, mostly termed "*rough iron fyned*," was produced in a blast-furnace and was subsequently submitted to refining in a finery hearth to eliminate impurities and carbon. This refined iron was bought by the King at £2 13*s*. 4*d*. per ton, and was delivered to Simon Ballard, one of the King's gunners at the Tower, who used it for casting gun shot at Newbridge. The shot differed in size and weight, ranging from 5 lb. each for "*serpentines*," which were cannon of the smallest type, to 34 lb. each for "*demi-curtows*," *i.e.*, cannon of middle type, and to large bullets of 225 lb. each for "*bombardelles*" or mortars. In addition, 200 small iron bullets were cast by him, each weighing a little less than $1\frac{5}{8}$ lb., apparently destined for hand-guns. The total weight of the 1100 bullets was 18 tons $4\frac{1}{2}$ cwt. 24 lb., and the cost of production £72 19*s*. 5*d*., of which £48 12*s*. 7*d*. was paid for the refined iron,

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Dr. Schubert is Historical Investigator to The Iron and Steel Institute.

[1] Rhys Jenkins, The Rise and Fall of the Sussex Iron Industry, *Transactions of the Newcomen Society*, vol. I, pp. 18–19, London, 1922.

[2] Rhys Jenkins, Ironfounding in England, 1490–1603, *ibid.*, vol. XIX, p. 37, London, 1940.

[3] E. Straker, Wealden Iron, pp. 43, 49, 147, 390, 395, London, 1931.

[4] The method was known early in the fifteenth century according to a pirotechnia (Feuerwerksbuch) of 1454, O. Johannsen, Eine Anleitung zum Eisenguss vom Jahre 1454, Stahl und Eisen, 1910, pp. 1374–1375.

[5] A. Conway, Henry VII's Relations with Scotland and Ireland, 1485–98, pp. 99 *et seq.*, Cambridge, 1932.

[6] Public Record Office, Patent Rolls 12 Henry VII, membrane 23d.

[7] Account of 1496–97, Public Record Office, Exchequer Treasury of the Receipt, Miscellaneous Books, vol. 8, pp. 49 and 79.

[8] *Ibid.*, pp. 49, 145, 150.

7*d.* for more iron supplied by Ballard, and £24 6*s.* 3*d.* for workmanship.[9]

By the various entries in the account of 1496–97 it is clearly shown that a blast-furnace and a forge were in existence at the end of 1496 on Crown property at Newbridge. This is the first English blast-furnace of which there is definite evidence.

The entrepreneur of the ironworks was the above-mentioned Henry Fyner, who apparently had invested the capital necessary for stock and supplies. Evidently he was identical with the Harry Fyner, also termed a goldsmith of Southwark, against whom a complaint was lodged by "*Peter Roberdes otherwise called Graunt Pierre, yerne fonder dwellynge in Hertfelde* (Hartfield) *in the Forest of Ashdowne.*"[10]

The complaint is not dated, but is sometimes wrongly ascribed to 1493. The approximate date, however, is between 1493 and 1500. Graunt Pierre also was a gunner at the Tower, and was mentioned as such on 16th May and 6th June, 1497.[11] A few months earlier (6th January) he received a reward of £1, on which occasion he was termed a "*founder.*"[12] In his complaint, Graunt Pierre stated that he had been arrested and laid in chains on an action brought against him by Fyner on account of an alleged debt. It is most unlikely that this would happen to a gunner in the Royal service, or that the imprisoned man would have been accepted into this service after his release. For this reason, the action appears to have taken place not before the later part of the year of 1497 or possibly even later. Graunt Pierre further stated that he had worked an iron-mill that was Crown property situated in the Forest of Ashdown, first alone from Christmas for 9 months and then jointly with Fyner for a period of equal length. The iron produced by him was delivered to Fyner at £3 per ton. The only furnace on record at that time, and belonging to the Crown, was at Newbridge in the parish of Hartfield. At Hartfield itself there was but a forge, first referred to in 1496 as possessed by Thomas Wildgose of Hartfield and worked by John Stile.[13] The rent paid by Graunt Pierre during the 1½ years of his tenancy was £20 per year, which is exactly the same as that paid by Pauncelett Symart from Michaelmas 1498 onwards for the ironworks at Newbridge.[14] By all this evidence it may safely be concluded that Graunt

A fireback cast in 1636. The blast-furnace shown in the bottom left-hand corner has the outer casing built with stones, strengthened with oak beams. (*Reproduced from "A History of Cast Iron in Architecture", by J. Gloag and D. Bridgewater, George Allen and Unwin Ltd.*, 1948)

[9] *Ibid.*, pp. 75, 79, 96, 110, 139, 150, 203.
[10] Public Record Office, Chancery Proceedings, Bundle 222, No. 112.
[11] Account of 1496–97, *loc. cit.*, pp. 132 and 158.
[12] Excerpta Historica, p. 110, London, 1831.
[13] E. Straker, *loc. cit.*, p. 245.—John Stile is also referred to as carrying iron from Hartfield to the Tower on 1st June, 1497. Account of 1496–97, *loc. cit.*, p. 145.
[14] Public Record Office, Duchy of Lancaster, Ministers' Accounts, Bundle 454, No. 7329.

Pierre's iron mill was identical with the ironworks at Newbridge, that he had rented it from Christmas 1496 to Midsummer 1498, and that after a short interval during his imprisonment, the new tenant became Pauncelett Symart.

The furnace at Newbridge is particularly remarkable as the place where, in 1509, guns of cast iron were successfully manufactured for the first time in English History by the above mentioned Pauncelett Symart.[15] The three iron guns cast by him were delivered to the Clerk of the Royal Navy at Portsmouth for the armament of the battleship "Le Souvereign."[16]

In the same year of 1509, an inventory of implements used at the ironworks of Newbridge was compiled.[17] As this is the most ancient inventory of an English blast-furnace and forge, and has not been published before, it might be well worth publication now.

> "*Theis ben(e) the implement(es) and necessaryes with other toles of yron(e) belonginge to the Kyngs iron(e) milles wythyn(e) the forest of Asshedonne yn the countye of Sussex.*
>
> *Fyrst for the furnes II furgons of iron and a stokkarde of iron(e) whyth II shovyll(es) of iron(e) and a chrochett of iron.*
>
> *It(em) for the fyner II furgons and a ranggarde of iron(e) wyth III peyer of tong(es) and an hoke of iron.*
>
> *It(em) for the greate hamer (and an anvell and grete ryng of iron for the hamer helfe)* V peyer of tong(es). It(em) II furgons of iron(e) and an iron hoke.*
>
> *It(em) a peyer of bellows for the furneys.*
>
> *It(em) a peyer of bellowes for the fyner.*
>
> *It(em) a peyer of bellowes to the hamer.*"

* The phrase in parentheses was added above the line, but apparently by the same writer.

The first section of the inventory refers to implements employed at the furnace. The "*stokkarde*" was an iron stoker, in later inventories mostly termed "*ringer*" or "*wringer*." The stoker and the *furgons* or *fourgons* were long iron bars used for clearing the bottom and sides of the furnace hearth, and particularly the tuyere hole from adherent slag. The "*chrochett*" was a bent hook of iron for drawing away the liquid slag, which ran out of the furnace over the dam plate. The removal of slag with an iron hook is referred to as an essential part of the founder's work in a description of ironmaking at Vendeuvre, near Troyes in Champagne, in a Latin poem "Ferraria" composed in 1517 by Nicolaus Bourbon.[18] Shovels were required mainly for filling charcoal and ore into bags for charging, but also for making moulds in the sand for casting.[19]

The "*fyner*" worked at the finery hearth of the forge in which the process of converting pig iron, obtained from the furnace, into malleable iron was conducted. With *furgons* the metallic mass, which, after the pig had been melted down, coagulated into a semi-solid state at the bottom of the hearth, was raised to the top of the fire, so as to expose it to the decarburizing blast of the tuyere. The "*ranggarde*" (or ringer) served for keeping the molten matter in motion by stirring, which was a most essential part in the process of refining. At the end of the operation the ball of refined iron was taken out of the finery hearth with an iron hook and tongs, and was dragged along an iron path to the hammer and anvil to be consolidated and shaped into the size required. In between the various hammerings, the iron was reheated in a second hearth termed a "*chafery*" (from French *chaufferie*) in which it was manipulated with *furgons* and a hook. On the anvil the heated iron was held with tongs.

In the last year of Pauncelett Symart's tenancy the ironmills apparently were in a bad state of repair, as a commission was appointed to examine whether the buildings were "*tenantlike*."[20] Pauncelett Symart was constantly in arrears with his rent from 1498 and it took thirty years until his debt was paid off completely.[21] Apparently the rent was too high for profitable working. When Humfrey Walcott took over from Symart in 1512, the rent was lowered to £14 13*s*. 4*d*. per year.[22] He was the King's "*gunfounder*" and made iron bullets for new guns of copper in the same year, for which he was paid on 12th January, 1512.[23] Considering the poor state of repair of the ironworks it still appeared impossible to make a profit. As a result, when the term of Walcott's lease expired in 1519, it was not possible to find a new tenant until 1525.[24]

On 24th March 1525 the ironmills were leased for 21 years to Thomas Boleyn, Viscount of Rochefort and later Earl of Wiltshire, who was the Master Forester of Ashdown Forest at that time. The rent was reduced to £4 per year, which was one-fifth of the original rent.[25] On 14th August, 1563, the whole forest of Ashdown, including the ironworks, was leased to Richard Sackville for 40 years with liberty to dig for iron ore and utilize the wood of the trees except oak and ash.[26] After the lease had expired in 1603, the ironworks were not mentioned in the accounts.[27]

So in 1603 the story of the first English blast-furnace came to an end.

[15] H. Schubert, The First Cast-Iron Cannon Made in England, *Journal of The Iron and Steel Institute*, 1942, No. II, p. 134P.

[16] Public Record Office, *loc. cit.*, Bundle 455, No. 7331.

[17] Public Record Office, Duchy of Lancaster, Ministers' Accounts, Bundle 455, No. 7331 (*in dorso*).

[18] Published together with Bourbon's other poems in "Nicolai Borbonii Nugae," Paris 1533. An abbreviated translation into English is supplied by E. Straker, *loc. cit.*, pp. 41–43.

[19] Account of the ironworks at Rievaulx in Yorkshire, of 1578. Belvoir Castle, Account No. 527. The author is greatly indebted to His Grace the Duke of Rutland for permission to study these documents.

[20] Public Record Office, Book of Commissions, No. 95, fol. 11.

[21] Public Record Office, Duchy of Lancaster, Ministers' Accounts Bundle 454, Nos. 7329–7344.

[22] *Ibid.*, No. 7332.

[23] Public Record Office, Exchequer Q.R., Bundle 55, No. 29.

[24] Public Record Office, Duchy of Lancaster, Ministers' Accounts Bundle 454, Nos. 7337–7342 (*inoccupata pro defectu reparationis ac pro eo quod nullus conducere voluit dicta molendina*).

[25] *Ibid.*, Bundle 445, No. 7160.

[26] *Ibid.*, Bundle 449, No. 7214.

[27] *Ibid.*, Bundle 451, No. 7250 and Bundle 459, No. 7420.

Corrosion of Welded 18/8 Type Chromium–Nickel Steels in Concentrated Nitric Acid

By H. T. Shirley, B.Sc., A.R.C.S., and C. G. Nicholson, A.Met.

SYNOPSIS

An increasing desire to use 18/8 type Cr–Ni steels with high concentrations of nitric acid, often at elevated temperatures, has made it important to ascertain their behaviour under such conditions. Service experience with welded vessels and the use of the Huey test have both indicated the serious selective attack to which titanium-stabilized material may be susceptible, and this paper is mainly a study of the influence of welding on this susceptibility. It is considered that the mechanism is essentially an extension of the well-known intercrystalline corrosion from boundary chromium impoverishment. The conditions are much more severe than those covered by the normal sulphuric-acid/copper-sulphate test solution, and in these conditions titanium is a less effective stabilizer than niobium.

With duplex titanium-stabilized steels, attack was most severe at delta/gamma boundaries, leading to initial dislodgement of the delta material. Slower attack occurred between austenite grains of sensitized titanium-stabilized material, even without delta-phase, and niobium-stabilized steels could be made susceptible to attack by sufficiently high solution treatment followed by more prolonged sensitization at 650° C.

It is concluded that 18% Cr, 8–13% Ni steels with a 10/1 niobium–carbon ratio should give welds having a satisfactory resistance to this type of attack, even in cases of double welding, such as the sealing welds inside vessels.

DURING the last 20 years, very large tonnages of titanium-stabilized 18/8 type Cr–Ni steels have been used in plant dealing with the manufacture, storage, and utilization of nitric acid. A large proportion of this plant has been of welded construction, and the few unexpected failures which have been experienced have been with welded equipment working in the more severe ranges. The main object of this paper is to study this type of failure, and to find the type of steel best suited to service under such conditions.

A few years ago there was a serious failure of a storage tank after 3½ years' service with 96% acid.* The 20-ft. dia. tank was 20 ft. high and was built of 18/8 Cr–Ni–Ti steel 10-gauge sheets, strengthened by mild-steel straps. Small leaks developed in service, particularly near the top of the tank, and detailed inspection eventually revealed severe attack associated with the welds, about 50% of which required rewelding. The attack had occurred primarily in the plate material immediately adjacent to the weld metal, and was associated with selective removal of the δ-constituent of the microstructure. In its location and form this attack was reminiscent of unexpectedly high attack rates found in previous laboratory tests with boiling 70% HNO_3. Parallel tests with hydrochloric, phosphoric, and acetic acids indicated that the effect was peculiar to the hot concentrated nitric acid. The attack was selective, as in the service failure, and was greatly reduced by water-quenching the ½-in. dia. test specimens, instead of air-cooling, after 1050° C. softening. These observations suggested that boiling 70% HNO_3 might be used as an accelerated test to investigate the mechanism of failure of the tank material in the cold 96% acid. In practice, periods of up to seven days in boiling 70% HNO_3 were found to produce attack which, in type and magnitude, satisfactorily reproduced the effects observed in service.

Two other aspects make this type of laboratory test of particular interest. There is a growing requirement in chemical engineering to use these steels with nitric acid under more severe conditions of concentration and temperature. There is also the widespread use, in America, of the Huey test as a check on general quality and condition. This test of five 48-hr. periods in boiling 65% HNO_3 was initially claimed by Huey[1] to show "the resistance of the sample tested to the corroding solution used under the conditions of test made," but it has become widely used as an acceptance test in respect of intercrystalline corrosion susceptibility, frequently with material intended for entirely different service conditions. It is realized that this generalized application is unsatisfactory, and Brown[2] has recently reviewed the position. Previously, Stewart[3] concluded that titanium-stabilized steels were particularly sensitive to boiling concentrated nitric acid. He found that a 0·05% C 18/10 Cr–Ni–Ti steel, sensitized for 2 hr. at 680° C., showed a higher rate of attack in boiling 65% HNO_3 than did an unstabilized 0·07% C 18/8 steel, whereas niobium-stabilized material behaved satisfactorily. On the other hand, both types of stabilized material gave good results during the $H_2SO_4/CuSO_4$ test for intercrystalline corrosion susceptibility, and did not show the acceleration in nitric acid of 45% concentration or less. Also, it has been established that the titanium-stabilized steel is entirely satisfactory in a very wide variety of conditions. This lack of correlation between response to the Huey test and general behaviour to other types of service conditions has been emphasized by Comstock[4] in the A.S.T.M. 1949 Symposium on Evaluation Tests for Stainless Steels, which contains considerable data and discussion on the use of the Huey type of test, and a summary by LaQue.[5]

* Throughout the paper, all strengths of acid are given in terms of weight-weight percentage of real HNO_3 to water.

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The subject of the attack by concentrated nitric acid on chromium–nickel stainless steels is extensive and complicated, and this paper deals with the intensive attack liable to occur immediately adjacent to the welds, which presents the most serious service problem. Results from a more generalized study on unwelded material are included where necessary to the argument, but a more complete discussion of these aspects will be published subsequently.

WELDED 18/8 Cr–Ni–Ti STEEL FROM STORAGE TANK FOR 96% HNO_3

Two samples were received from the tank in which cold 96% HNO_3 had been stored for 3½ yr. The tank had been fabricated by arc welding, a main butt weld being applied from the outside and a sealing run on the inside, using 18/8 Cr–Ni–Nb electrodes. Attack had proceeded from the inside of the tank. The general appearance of one of the samples is illustrated in Fig. 1, which shows the very severe attack immediately adjacent to the weld, and also a zone of more shallow grooving in a position where intercrystalline corrosion susceptibility would be expected in unstabilized steel.

The analyses of the two samples were as follows :

	C, %	Si, %	Mn, %	Cr, %	Ni, %	W, %	Ti, %
Plate (1)	0·15	0·63	0·31	18·35	7·95	0·65	0·62
Plate (2)	0·12	0·71	0·84	17·76	7·83	0·56	0·52

Figure 2*a* shows an etched section of the various zones of attack. The niobium-stabilized sealing weld, which had apparently suffered very little attack, had been deposited with a considerable offset, and there was a correspondingly large difference in behaviour of the plate material on the two sides. It is shown on p. 113 that there is a general relationship between the degree of offsetting and the extent and distribution of the attack, due to the complex heat-treatment effects involved. The extent of attack is controlled by the accessibility of the susceptible material to the corroding medium, since coverage by the weld metal or by a more resistant surface layer can markedly delay, or even indefinitely prolong, the onset of accelerated attack on the more vulnerable material beneath. It was therefore decided to carry out tests on sections, using boiling 70% HNO_3 to give a suitably accelerated action.

The test procedure adopted was as follows : A 2 in. × ½ in. sample, with the weld in the middle of the 2-in. length, was cut from the plate, the longer edges were polished, and the sample was boiled for an appropriate period in 80 ml. of 70% HNO_3. The edges were then lightly polished and etched* to reveal the nature and extent of the attack. Figure 2*b* shows the effect of this procedure (boiling in acid for 24 hr.) on the section illustrated in Fig. 2*a*. On the side where the sealing weld has the greater overhang, severe attack is limited to a narrower zone immediately next to the weld. This attack has completely removed the δ-constituent, and removal of some austenite crystals has occurred (*see* Fig. 3). In the region corresponding to the ordinary intercrystalline corrosion zone of welded unstabilized steels, the attack has again resulted in preferential removal of the δ-constituent but is much less pronounced (Fig. 4) ; over the remainder of the plate material there appears to have been very little attack.

From these and other similar observations on service samples, it was concluded that accelerated boundary attack is characteristic for these nitric acid solutions, and that in duplex plate it is particularly severe around the δ-constituent. It seemed probable that the attack was related to chromium depletion through carbide precipitation, similar to but probably much less severe than that giving rise to intercrystalline attack in the $H_2SO_4/CuSO_4$ solution with welded unstabilized steels. The various susceptibilities observed for the different zones would then correspond to the complex series of heat-treatment effects produced by the double welding, since it is known that treatment above 1100° C. can considerably intensify response to later sensitization treatment in the 500–800° C. range. For example, softening treatment at 1200° C. applied to titanium-stabilized 18/8 Cr–Ni steel can cause this material to fail, on subsequent treatment for ½ hr. at 650° C. followed by the $H_2SO_4/CuSO_4$ test, whereas no such susceptibility would be observed with initial 1050–1100° C. softening. Therefore, the extremely high-temperature treatment given immediately adjacent to the first weld would be expected to create a zone of special sensitivity to precipitation during cooling through the lower temperature range, or during the application of this sealing weld. There is also the possibility of incomplete stabilization in this zone, owing to loss of effective titanium by oxidation during welding.

COMPARISON OF WELDED SAMPLES IN TITANIUM- AND NIOBIUM-STABILIZED STEELS

The satisfactory behaviour of the niobium-stabilized weld metal in the tank samples made it of obvious interest to examine the behaviour of welded samples made entirely from this type of steel. Such material differs from the titanium-stabilized steel in being fully austenitic, and it was therefore decided to test also a more stable austenitic composition of the 18/14 Cr–Ni–Ti type. Both types of steel were compared with the corresponding niobium- or titanium-stabilized steel (*see* Table I, steels *A–D*).

Table I—ANALYSES OF STEELS TESTED

Steel	C, %	Si, %	Mn, %	Cr, %	Ni, %	Ti, %	Nb, %
A 19/8 Cr–Ni–Ti	0·15	0·68	0·33	19·15	7·75	0·69	...
B 18/14 Cr–Ni–Ti	0·12	0·96	0·40	18·36	14·33	0·56	...
C 18/9 Cr–Ni–Nb	0·13	0·67	0·48	18·32	9·13	...	1·32
D 18/13 Cr–Ni–Nb	0·11	0·70	1·30	17·96	13·40	...	1·48
E 18/8 Cr–Ni–Ti	0·09	0·69	0·31	17·44	8·40	0·63	...
F 18/8 Cr–Ni–Ti	0·15	0·68	0·44	18·14	8·38	0·73	...
G 19/8 Cr–Ni–Ti	0·11	0·52	0·33	19·15	7·75	0·69	...
H 19/8 Cr–Ni–Nb	0·12	0·61	0·44	18·53	7·80	...	1·21
I 18/10 Cr–Ni–Nb	0·11	0·54	0·54	17·72	9·95	...	1·14
J 18/11 Cr–Ni–Ti	0·07	0·55	0·55	17·48	11·33	0·63	...

* Except where otherwise indicated, all etching has been carried out in a solution containing 20 ml. of 10% chromic acid solution with 80 ml. concentrated hydrochloric acid, used at room temperature.

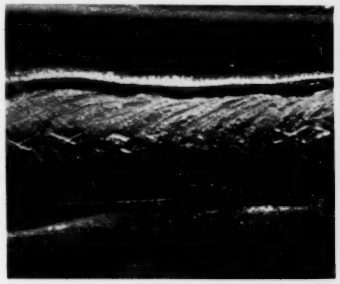
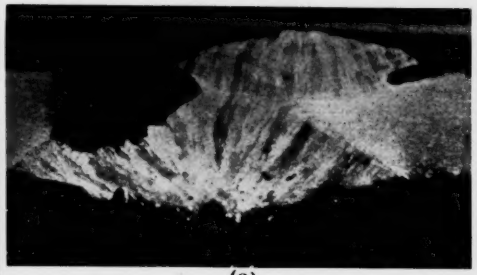
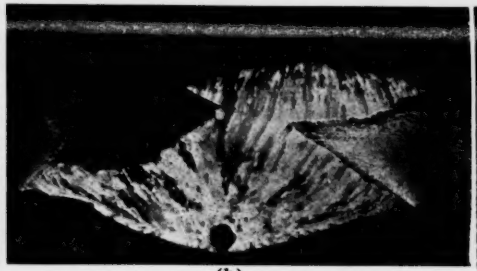


Fig. 1—General appearance of sample from welded tank × 2



(a)



(b)

Fig. 2*—Sections of tank sample : (*a*) Etched without further treatment ; (*b*) etched after 24 hr. in boiling 70% HNO_3 × 5

Fig. 3—Detail of attack near sealing weld in Fig. 2*b* × 500

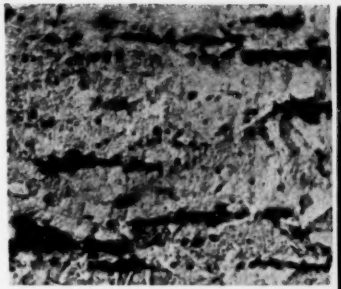
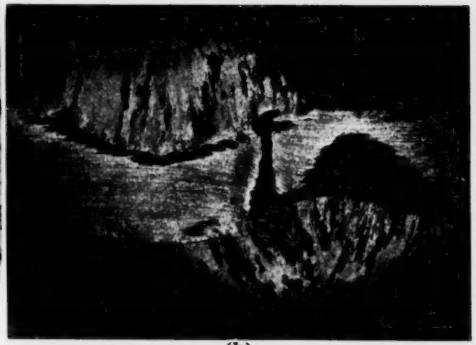
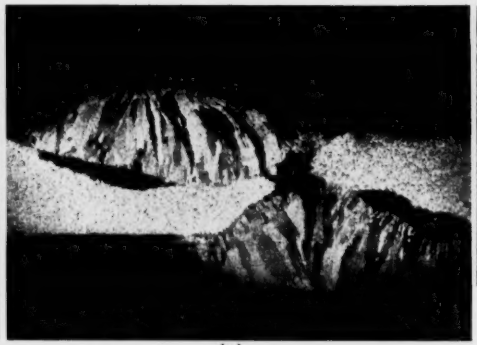


Fig. 4—Detail of 600–700° C. region on right of Fig. 3 × 500



(b)



(a)

Fig. 5*—Sections of welds after 7 days in boiling 70% HNO_3 ; lightly polished and etched : (*a*) 19/8 Cr-Ni-Ti steel (*A*) ; (*b*) 18/14 Cr-Ni-Ti steel (*B*) × 6

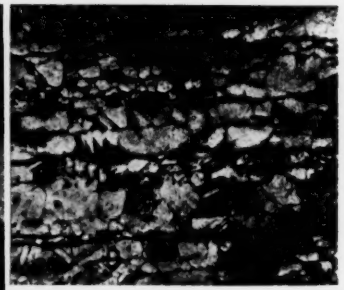
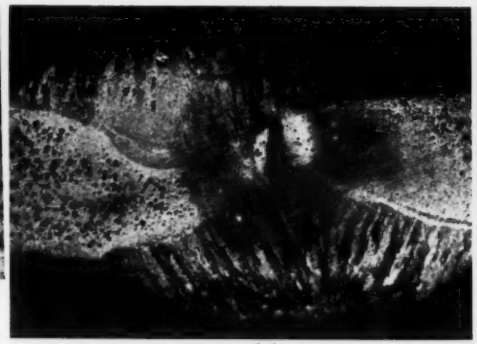
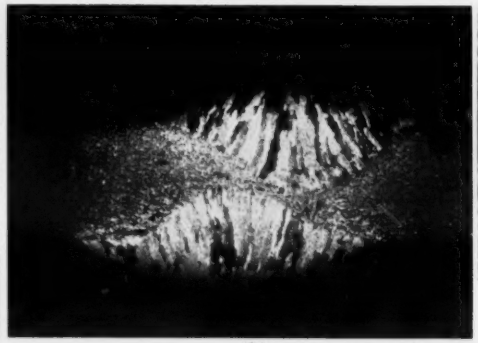


Fig. 6—Area near first weld in Fig. 5*a* × 200

Fig. 7—Detail from Fig. 5*b* × 200



(a)



(b)

Fig. 8*—Sections of welds after 7 days in boiling 70% HNO_3 ; lightly polished and etched : (*a*) 18/9 Cr-Ni-Nb steel (*C*) × 7 ; (*b*) 18/8 Cr-Ni-Ti steel (*E*) × 6

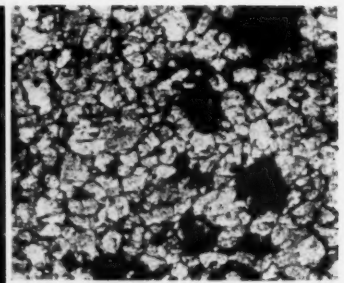


Fig. 9—Detail from area some distance away from weld zone in Fig. 8*a* × 200

* The second, or sealing, weld is at the top

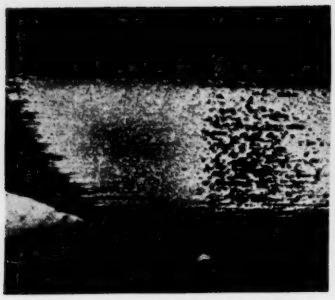
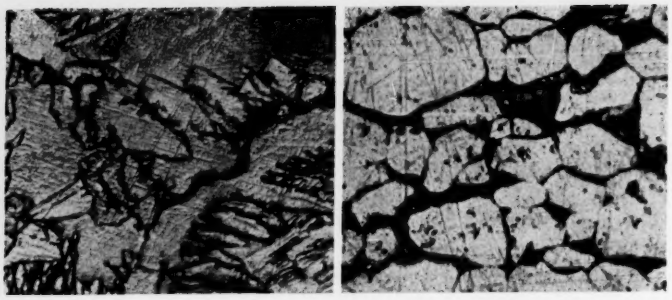
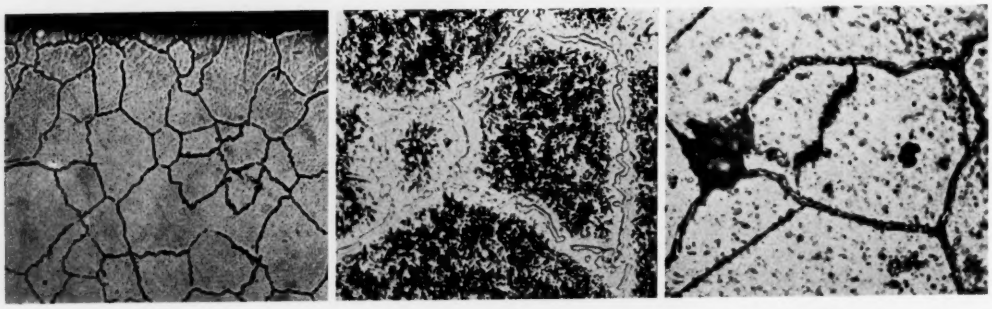


Fig. 10—Section of weld of 18/8 Cr-Ni-Ti steel (*E*), after 7-day test in boiling 70% HNO_3 with acid renewal at each 24-hr. cycle × 7



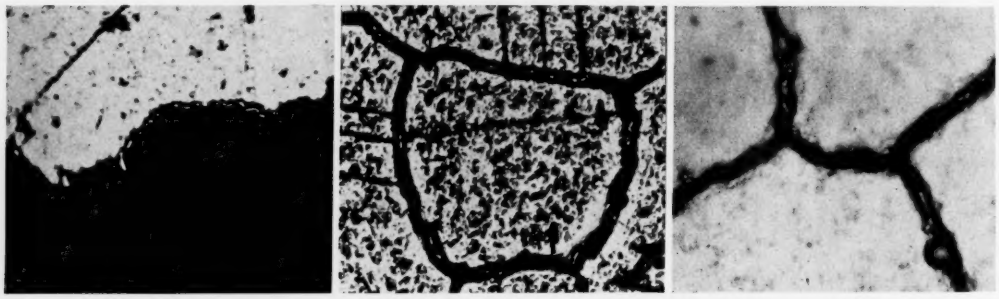
(a) (b)

Fig. 11—Microstructures of taper-treated 19/8 Cr-Ni-Ti steel (*A*) : (*a*) 1390° C. region, after 36 hr. in boiling 70% HNO_3 ; (*b*) 1325° C. region, given 5 min. at 650° C. and 3 hr. in boiling 70% HNO_3 × 500



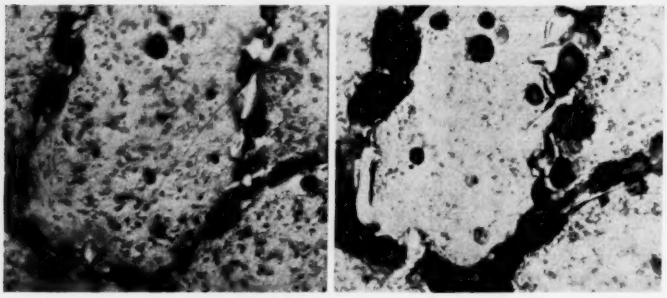
(a) (b) (c)

Fig. 12—Microstructures of 0·49% C 18/10 Cr-Ni steel : (*a*) Polished section × 100 ; (*b*) as in (*a*), but etched in HCl/HNO_3 × 500 ; (*c*) section after 45 min. in $H_2SO_4/CuSO_4$ testing solution × 500



(a) (b) (c)

Fig. 13—Microstructures of 0·49% C 18/10 Cr-Ni steel : (*a*) Section from Fig. 12*c* after fracturing × 500 ; (*b*) section after 4 hr. in boiling 70% HNO_3 × 500 ; (*c*) section after treatment for 6 hr. at 950° C., water-quenched, and tested for 7 days in $H_2SO_4/CuSO_4$ testing solution × 1000



(a) (b)

Fig. 14—Microstructures of sections of 0·49% C 18/10 Cr-Ni steel (6 hr. at 950° C., water-quenched) after treatment in boiling 70% HNO_3 for : (*a*) 18 hr. ; (*b*) 30 hr. × 1000

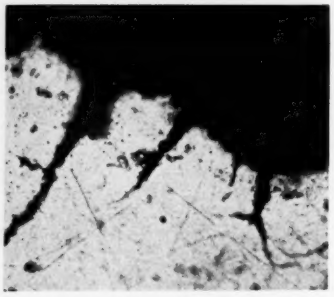


Fig. 15—Etched section of 18/10 Cr-Ni-Nb steel (*I*) after treatment at 1150° C., air-cooled, followed by 24 hr. at 650° C., and tested in boiling 70% HNO_3

All the welds were made with 10-gauge plate, using 18/8 Nb-type electrodes.

The test procedure was similar to that described on p. 112, but the period in boiling 70% HNO_3 was increased to seven days. This was a very drastic test, as the build-up of corrosion products in the limited volume of solution tended to produce considerable attack even on normal plate material away from the weld-affected zone; however, it showed quite clearly the tendency for local acceleration to occur near the weld. After the test, the samples were polished sufficiently for examination and were then etched.

19/8 Cr–Ni–Ti Steel—The weld region is shown in Fig. 5*a*, which illustrates the general similarity in distribution of the major attack and the attack in the service welds; Fig. 6 is a detailed view showing the selective nature of the attack. Although the attack was most severe around the δ-constituent, groups of austenitic crystals have also disappeared. Examination of the middle section cut through the longitudinal centre of the weld showed no severe attack, as here the plate surface retains a high resistance even in the high-temperature zone, presumably because of the subsequent rapid cooling through the precipitation range. It is this feature that delays the onset of the rapid attack leading to service failure, and it probably accounts for much successful service during which early failures would otherwise have occurred.

18/14 Cr–Ni–Ti Steel—This material showed no signs of δ-phase, either magnetically or in the microstructure. Nevertheless, there was severe attack adjacent to the weld (Fig. 5*b*). This attack was primarily intercrystalline (*see* Fig. 7) around coarse-grained material produced by the local high-temperature treatment in welding. Examination of a mid-section showed that, in this case, attack had penetrated into the coarse zone from the face of the plate to a depth of about 0·02 in.

18/9 Cr–Ni–Nb Steel—This steel is fully austenitic. A certain amount of intercrystalline pitting attack was distributed generally over the plate section, except immediately adjacent to the weld, where there was evidence of protective action from the heat-treatment during welding (Figs. 8*a* and 9). The normal 72-hr. $H_2SO_4/CuSO_4$ test for intercrystalline corrosion produced no observable effect in this material, so that the general tendency to intercrystalline edge breakdown is probably not important under most service conditions.

18/13 Cr–Ni–Nb Steel—The effect was generally similar to that on the corresponding 18/9 steel *C*, but with rather more severe intercrystalline attack on the plate section. There was again some protection of the material immediately adjacent to the weld.

The results from these tests confirmed the general indications as to occurrence and distribution of severe selective attack found in the service welds of the titanium-stabilized steels. Under the drastic conditions of the laboratory nitric acid test, intercrystalline attack and pitting on the section occurred even with the niobium-stabilized steels, but in these steels the attack decreased in the immediate neighbourhood of the weld (the region in which the titanium-stabilized steels were so severely affected). If the severe local sensitization of the titanium-stabilized steels is caused by chromium impoverishment resulting from carbide precipitation, then the action of niobium in forming a stable carbide complex would appear to be more effective than the corresponding action of titanium, which permits sufficient precipitation of chromium to lower the resistance to nitric acid (although the response to the $H_2SO_4/CuSO_4$ test and to most service conditions remains satisfactory).

INFLUENCE OF ACID CONCENTRATION AND RENEWAL

In regard to nitric acid plant, it was obviously of interest to investigate the effect of concentration of acid on the severity of the accelerated weld-zone attack. Welded samples were prepared from $\frac{1}{8}$-in. thick material of the 18/8 Cr–Ni–Ti, 18/9 Cr–Ni–Nb, and 18/13 Cr–Ni–Nb steels (*see* Table I, steels *E*, *C*, and *D*), from which were cut 2 in. × $\frac{1}{2}$ in. specimens with the weld across the width and in the middle of the length. All welds were made with 18/8 Nb-type electrodes. The longer edges were micro-polished before test, as in the earlier qualitative tests. Each sample was immersed in 80 ml. of the appropriate acid, which was then boiled continuously for seven days. Solutions of 70%, 60%, 50%, and 30% HNO_3 were used, and a set of 2 in. × $\frac{1}{2}$ in. unwelded samples was included in the 70% acid, for comparison. After test, the loss of weight was determined and the samples were measured for loss of thickness of the sheet material. The results are given in Table II.

Table II—TOTAL LOSSES IN 7-DAY CONTINUOUS TESTS

Loss in weight is given as total for 2 in. × $\frac{1}{2}$ in. × $\frac{1}{8}$ in. samples, and loss in thickness as total for the sheet material

Steel	Unwelded Sample	Welded Samples			
	70% HNO_3	70% HNO_3	60% HNO_3	50% HNO_3	30% HNO_3
E 18/8 Cr–Ni–Ti	2·96 g. 0·015 in.	3·79 g. 0·017 in.	2·38 g. 0·009 in.	0·54 g. 0·002 in.	0·12 g. 0·001 in.
C 18/9 Cr–Ni–Nb	1·52 g. 0·008 in.	1·20 g. 0·005 in.	0·16 g. 0·001 in.	0·10 g. 0·001 in.	0·69 g. 0·001 in.
D 18/13 Cr–Ni–Nb	0·67 g. 0·004 in.	0·68 g. 0·003 in.	0·24 g. 0·001 in.	0·13 g. 0·001 in.	0·04 g. 0·001 in.

Table III—RATE OF ATTACK ON WELDED SAMPLES IN 70% HNO_3 WITH ACID RENEWAL AT EACH 24-hr. CYCLE

Loss in weight is given as total for 2 in. × ½ in. × ⅛ in. samples, and loss in thickness as total for the sheet material

Steel	Loss in Weight, g., After Cycle							Total Loss in Weight, g.	Total Loss in Thickness, in.
	1	2	3	4	5	6	7		
E 18/8 Cr–Ni–Ti ...	0·0452	0·0765	0·0718	0·1160	0·1103	0·1200	0·1316	0·6714	0·003
C 18/9 Cr–Ni–Nb ...	0·0365	0·0342	0·0327	0·0234	0·0249	0·0248	0·0315	0·2080	0·001
D 18/13 Cr–Ni–Nb ...	0·0179	0·0190	0·0250	0·0234	0·0235	0·0251	0·0232	0·1571	0·001

Although the loss in weight for the 18/8 Cr–Ni–Ti steel fell considerably between 60% and 50% HNO_3, the weld-zone attack was still very severe at 50%. With the 30% HNO_3, however, the weld effect became relatively slight (*see* Fig. 8*b*), although the selective boundary attack was still evident. The niobium-stabilized materials, as before, showed intercrystalline edge pitting, less in the neighbourhood of the weld than elsewhere. The degree of this attack fell off steadily with decreasing acid concentration, until it was not much more than a heavy etch in the 30% HNO_3. The losses in 70% HNO_3 were generally of the same order for welded and unwelded samples, the attack on the latter being similar to that on the material away from the weld-zone in the former.

In view of the grain-loosening effect of the selective attack, it seemed probable that some acceleration in the rate of weight loss would occur with time, in the earlier stages of the tests. This possibility was examined by weighing samples every 24 hr. throughout a 7-day test. At the same time, it was recognized from parallel studies on unwelded samples that conditions in the later stages of a prolonged test, without change of the rather limited volume of acid, become much more severe, because of accumulated corrosion products in the solution. To minimize this complication, and also to obtain some indication of the degree to which attack in the continuous test was accelerated by absence of acid change, the acid in this series was changed at each weighing. Steels *E*, *C*, and *D* were tested using 70% HNO_3. The results are given in Table III.

The change of acid decreased the overall attack to about 20% of the attack in the continuous test. There was no progressive change in rate with time for the 18/9 Cr–Ni–Nb steel, and only a relatively small increase for 18/13 Cr–Ni–Nb steel during the first two days. On the other hand, the 18/8 Cr–Ni–Ti steels showed a progressively increasing rate, the rate of attack in the 7th cycle being about three times that in the 1st cycle.

Although changing the acid greatly reduced the overall losses, the 18/8 Cr–Ni–Ti steel still showed very heavy attack in the weld zone ; also, intercrystalline attack was evident in the region corresponding to the usual intercrystalline corrosion zone for unstabilized steels (Fig. 10).

STUDIES WITH TAPER-TREATED SAMPLES

For a further study of the effects of complex heat-treatments, taper-treated samples were prepared. The first sample, from 19/8 Cr–Ni–Ti steel *A* (Table I), was a 5 in. × ¼ in. strip cut from 10-gauge sheet ; it was treated for 30 min. in an electric tube furnace with a considerable temperature gradient, and was then water-quenched. During treatment, thermocouples attached at 1-in. intervals registered the temperature, which rose from 995° C. to 1460° C., at which point considerable fusion occurred. By interpolation, positions corresponding to 1050°, 1125°, 1250°, and 1325° C. were selected for detailed study of the relation of attack to microstructure. For this investigation, sections were polished before and after treatment for 5 min. at 650° C. and were examined after various periods in the boiling 70% HNO_3.

In the absence of 650° C. treatment, samples which were boiled in 70% HNO_3 for 36 hr. showed only a normal structural etch at the four positions, and no selective attack was observed until the region corresponding to the solidus temperature of 1390° C. was reached, when slight local boundary attack was noted (Fig. 11*a*). After 650° C. treatment, however, selective attack appeared at the lower temperatures ; the appearance of the 1325° C. region after 3 hr. in the acid is shown in Fig 11*b*. The attack fell off progressively with decreasing initial treatment temperature, becoming very slight in the 1050° C. region even after 6 hr. in the acid.

The corresponding niobium-stabilized steel was much less affected. A taper-treated sample, prepared from steel *C* (Table I) and treated at 650° C., showed only a slight intercrystalline etch in the 1325° C. region and a rather deeper intercrystalline etch in the 1050° C. region, after 24 hr. in acid. In the 1450° C. region, where considerable fusion had occurred, selective attack was limited to a deep structural etch ; this agrees with the good resistance shown by the 18/8 niobium-weld metal.

CARBIDE BEHAVIOUR IN UNSTABILIZED HIGH-CARBON 18/10 Cr–Ni STEEL

Although intercrystalline attack in the H_2SO_4/$CuSO_4$ solution is caused by chromium impoverishment in the steel immediately adjacent to precipitated chromium-rich carbides in the boundaries, it was thought that nitric acid might produce more severe attack on the carbides themselves. In normal analytical practice, when these steels are dissolved in HCl it is usual to add HNO_3 to decompose the carbides. If, under the present conditions, the concentrated HNO_3 produced serious attack on the carbides, the intergranular or interconstituent corrosion which was observed might result. Differences between titanium- and niobium-stabilized materials might then be related to the relative

resistance of carbides towards such attack, since carbide decomposition is more difficult in niobium-stabilized material.

It was not practicable to check this hypothesis by direct micrographic observation of normal steels, because intergranular films would be too thin for the necessary detailed observation. Therefore an indirect approach was made, using a sample of high-carbon unstabilized steel. The carbides from such steels are dissolved more easily than the carbides from stabilized steels, so that the behaviour of the precipitated carbide in this experiment should indicate the maximum probable effect from direct attack on the carbide.

A sample of large-grained very-high-carbon strip was used ; the material was 0·025 in. thick, and had the composition : C, 0·49% ; Cr, 17·35% ; Ni, 10·47%. There was an extremely heavy precipitation of carbide at the crystal boundaries (*see* Figs. 12*a* and *b*), so that severe intercrystalline attack by $H_2SO_4/CuSO_4$ solution* was not surprising. Attack for as little as 5 min. loosened some of the smaller crystals, and after 45 min. the sample was readily crumbled. Despite complete weakening of boundaries at this stage, there was negligible attack on the carbide particles, some of which can be seen (Figs. 12*c* and 13*a*) clinging to one of the boundaries after fracture.

Boiling in 70% HNO_3 produced a much less spectacular attack, although there was appreciable grain-boundary acceleration. Figure 13*b* shows a typical area after 4 hr. in the acid. There was no indication that attack had progressed deeper than the visible effects, the sample remaining quite coherent. There was broad intergranular channelling, with simultaneous but slower attack on the carbide particles, many of which had been removed by undercutting after about 2–3 hr. attack. The particles remaining after 4 hr. suggested appreciable loss by attack on the carbide itself, although this was obviously not the primary cause of the boundary attack.

* Used as a boiling solution containing 98 g. of H_2SO_4 and 110 g. of $CuSO_4$ per litre.

The susceptibility to intercrystalline attack was reduced by treatment for 1 hr. at 900° C. followed by air-cooling. In this condition, exposure for 3 hr. to the $H_2SO_4/CuSO_4$ solution left the sample quite firm against bending, but crumbling occurred easily after exposure for 24 hr. The rate of attack in HNO_3 was also reduced ; exposure for 8 hr. produced a very similar appearance to the 4-hr. attack on the earlier sample.

Very considerable stabilization against the $H_2SO_4/CuSO_4$ solution was achieved by treatment for 6 hr. at 950° C. followed by water-quenching. Samples treated in this way and tested for 24 hr. showed only slight etching. After 72 hr., slight intercrystalline channelling had become apparent, and exposure for one week produced intercrystalline attack of a similar order to that with the 4-hr. HNO_3 test on the original sample. Figure 13*c* illustrates this, and shows a few carbide particles persisting in the channels. The channel depth was estimated to be of the order of 0·001 mm. with a width of about 0·002 mm. The HNO_3 test now required about 14 hr. to produce an attack similar to the original at 4 hr. The same processes of uncovering and undermining were evident with only slight direct carbide attack (*see* Fig. 14).

It can therefore be concluded that the selective boundary attack in the HNO_3 test is essentially an attack on the steel and not on the carbide. The extremely rapid penetration of the $H_2SO_4/CuSO_4$ test with this steel in its original condition appeared to affect a very thin layer of steel, whereas HNO_3 attacked a much wider channel, with very much slower penetration. Appropriate heat-treatment prevented rapid $H_2SO_4/CuSO_4$ attack, leaving this reagent with an effect similar to but much slower than that of HNO_3. The attack by HNO_3 decreased much less spectacularly with heat-treatment, to about a quarter of its original rate

QUANTITATIVE TESTS ON UNWELDED SAMPLES

The micrographic and semi-quantitative work so far described gave sufficient indication of relative attack on the weld zones to provide an understanding of the mechanism and general susceptibility of the

Table IV

TESTS ON UNWELDED SAMPLES OF 18/8 Cr–Ni–Ti STEEL (*F*) IN BOILING 70% HNO_3

Initial Heat-Treatment	Surface Condition*	Loss in Weight After Single Treatment, g./sq. cm.	Loss in Weight, g./sq. cm., in 18 hr., After Second Treatment for 5 min.† at :				
			550° C.	650° C.	750° C.	850° C.	950° C.
1050° C., Air-Cooled	*a*	0·0004	0·0007	0·0003	0·0008	0·0009	0·0009
	b	0·0007	0·0007	0·0008	0·0008	0·0008	0·0010
	c	0·0008	0·0006	0·0006	0·0009	0·0009	0·0006
1150° C., Air-Cooled	*a*	0·0010	...	...	0·0011	...	...
	b	0·0008	...	...	0·0014	...	...
	c	0·0008	...	...	0·0033	...	...
1250° C., Air-Cooled	*a*	0·0004	0·0011	0·0176	0·0370	0·0013	0·0009
	b	0·0009	0·0059	0·0714	0·0612	0·0060	0·0012
	c	0·0043	0·0176	0·0908	0·1140	0·0435	0·0009

* (*a*) Emeried ; (*b*) re-emeried after test (*a*) ; (*c*) as tested in (*b*), without re-emerying
† The 550° and 650° C. treatments were given in salt baths, allowing 1 min. extra to reach temperature ; the 750–950° C. treatments were made in a muffle furnace, allowing an extra 5 min. to reach temperature ; all samples were air-cooled after these treatments

Table V

COMPARISON OF UNWELDED SAMPLES OF 19/8 Cr–Ni–Ti AND 19/8 Cr–Ni–Nb STEELS IN BOILING 70% HNO_3

Steel	Second Heat-Treatment	Surface Condition*	Loss in Weight, g./sq. cm., in 18 hr., After Initial Heat-Treatment at :		
			1050° C., Air-Cooled	1150° C., Air-Cooled	1250° C., Air-Cooled
G 19/8 Cr–Ni–Ti	None	*a*	0·0009	0·0007	0·0012
		b	0·0008	0·0009	0·0021
		c	0·0006	0·0006	0·0055
	5 min. at 650° C.	*a*	0·0008	0·0009	0·0011
		b	0·0007	0·0008	0·0306
		c	0·0008	0·0008	0·0699
H 19/8 Cr–Ni–Nb	None	*a*	0·0007	0·0007	0·0007
		b	0·0008	0·0008	0·0009
		c	0·0006	0·0005	0·0005
	5 min. at 650° C.	*a*	0·0008	0·0008	0·0009
		b	0·0009	0·0003	0·0010
		c	0·0005	0·0006	0·0007

* (*a*) Emeried ; (*b*) re-emeried after test (*a*) ; (*c*) as tested in (*b*), without re-emerying

various steels tested. It was felt, however, that the work should be supplemented by more quantitative tests, using samples uniformly treated to represent various combinations of heat-treatment effects, corresponding to the different weld zones.

The weight losses obtained with titanium-stabilized 18/8 Cr–Ni steel (*see* Table I, steel *F*), using various combinations of 5-min. solution treatment at temperatures from 1050° to 1250° C. followed by 5-min. sensitization treatments at temperatures from 550° to 950° C., are given in Table IV. These tests were made on emeried cylinders, $1\frac{1}{8}$ in. long, cut from $\frac{1}{2}$-in. dia. rolled bar. Each cylinder was tested for 18 hr. in 80 ml. of boiling 70% HNO_3, weighed, re-emeried, and again tested, followed by a third test after weighing but not re-emerying. The purpose of this last test was to indicate the development of increased attack by gradual intercrystalline penetration with eventual loosening of the grains, and it will be noted that acceleration of attack did occur in several samples.

There was no apparent increase in attack with increasing temperature of sensitization after initial heat-treatment at 1050° C. (*see* Table IV). After 1150° C. initial treatment a small increase in attack is evident in the samples undergoing 750° C. treatment in addition to the single treatment. The most serious increases, however, occurred after 1250° C. initial treatment, for all second treatments except that at 950° C. ; the maximum effect was at 650–750° C.

With the high initial treatment, even air-cooling without subsequent sensitizing treatment produced an effect. Micrographic examination of an air-cooled sample showed that intercrystalline attack had occurred and that the δ-constituent had been removed in the usual way. The more severe attack produced in 1250° C.-treated samples subsequently sensitized in the 550–850° C. range, showed similar but more pronounced characteristics.

In Table V, results are given for comparative tests with titanium- and niobium-stabilized 19/8 Cr–Ni steels (*see* Table I, steels *G* and *H*) in the form of $1\frac{1}{2}$ in. × $\frac{1}{2}$ in. samples from 10-gauge sheet. The initial treatment temperatures were 1050°, 1150°, and 1250° C, as before, but second treatment was limited to 5 min. at 650° C. ; the same test procedure was followed. Results for the titanium-stabilized steel were very similar to those obtained with steel *F*. The losses for the niobium-stabilized steel showed no acceleration of attack, so this material was also tested after longer treatments at 650° C. The samples used were from 10-gauge sheet of 18/10 Cr–Ni–Nb steel (Table I, steel *I*) and were treated at 650° C. for $\frac{1}{2}$ hr. and 24 hr. ; results are given in Table VI. It is evident that the niobium-stabilized material can be made to behave similarly to the titanium-stabilized steel by longer treatment at

Table VI

TESTS ON UNWELDED SAMPLES OF 18/10 Cr–Ni–Nb STEEL IN BOILING 70% HNO_3

Second Heat-Treatment	Surface Condition*	Loss in Weight, g./sq. cm., in 18 hr., After Initial Heat-Treatment at :		
		1050° C., Air-Cooled	1150° C., Air-Cooled	1250° C., Air-Cooled
None ...	*a*	0·0008	0·0010	0·0008
	b	0·0008	0·0008	0·0006
	c	0·0005	0·0005	0·0004
$\frac{1}{2}$ hr. at 650° C.	*a*	0·0007	0·0008	0·0010
	b	0·0010	0·0008	0·0008
	c	0·0003	0·0005	0·0006
24 hr. at 650° C.	*a*	0·0008	0·0050	0·0058
	b	0·0011	0·0044	0·0261
	c	0·0017	0·0288	0·0691

* (*a*) Emeried ; (*b*) re-emeried after test (*a*) ; (*c*) as tested in (*b*), without re-emerying

650° C. The intercrystalline nature of the attack is illustrated in Fig. 15.

Finally, a series of specimens was prepared to study the effect of air-cooling after short periods at very high temperatures in the 1300–1390° C. range. For this purpose, 1½ in. × ½ in. samples were cut from 10-gauge sheets of 19/8 Cr–Ni–Ti, 18/11 Cr–Ni–Ti, and 18/10 Cr–Ni–Nb steels (*see* Table I, steels *G*, *J*, and *I*). The samples were treated in salt baths at 1300°, 1350°, and 1390° C. One set of samples was taken just up to temperature, the time required being about ½ min.; a second set was held at temperature for 30 sec. Tests were then carried out for 18-hr. periods in boiling 70% HNO_3 as before, and the results are given in Table VII.

With the 19/8 Cr–Ni–Ti steel there was a slight acceleration of attack after 30 sec. at 1350° C. and a much more pronounced acceleration after 30 sec. at 1390° C.; the remaining samples showed no increase. The 18/11 Cr–Ni–Ti steel was rather less affected, showing an increase only after 30 sec. at 1390° C. and not so pronounced as with the lower-nickel steel. The niobium-stabilized steel showed no increase throughout the series.

The structure of 19/8 Cr–Ni–Ti steel remained duplex throughout, and the 18/10 Cr–Ni–Nb steel remained fully austenitic. No δ-phase was detected magnetically in the 18/11 Cr–Ni–Ti steel treated for ½ hr. at temperatures below 1340° C., but the steel became increasingly magnetic as the treatment temperature was increased to 1390° C. With these short treatments the small amount of δ-phase formed at 1390° C. did not noticeably affect the essentially intercrystalline attack. Intercrystalline attack also occurred with the 18/8 Cr–Ni–Ti steel after treatment for 30 sec. at 1350° and 1390° C., and was accompanied by loosening of the δ-constituent. The attack on the 18/10 Cr–Ni–Nb steel showed no structural features. The boundary constituent in this steel was hard, as was shown by the shape of a micro-hardness impression passing across a boundary, and is presumed to be carbide.

CONCLUSIONS

The attack by concentrated nitric acid, which causes the early failure of welded titanium-stabilized Cr–Ni steels, is of an intergranular type. In duplex steels the attack is most severe at the γ/δ boundaries, resulting in initial removal of the δ-phase material. The dislodgement of austenitic grains which eventually occurs is found in material showing no indication of the presence of δ-phase.

These forms of intergranular attack occurred in steels which behaved satisfactorily in the H_2SO_4/$CuSO_4$ test and in a wide variety of service conditions; severe intergranular attack is apparently caused only by nitric acid.

With boiling 70% HNO_3, severe selective attack near welds occurred in all the titanium-stabilized steels tested. This type of attack did not occur in niobium-stabilized steels, although these were liable to severe intercrystalline attack after solution treatment at or above 1150° C. followed by prolonged sensitization (24 hr.) at 650° C.

Severe attack on welded titanium-stabilized steels occurred in zones that had received combinations of heat-treatment similar to those producing general susceptibility to intergranular attack in unstabilized 18/10 Cr–Ni steels. Unwelded samples showed maximum susceptibility after heat-treatment at 650–750° C. The effect of 5-min. treatments in this range, although relatively small after the 1050° C. solution treatment, became increasingly severe as the temperature of the solution treatment was increased to 1250° C., whilst after treatment at or above 1350° C., air-cooling 10-gauge sheet was quite sufficient to induce appreciable sensitivity. The existence of a sensitized zone immediately adjacent to the weld metal in welded samples is therefore to be expected.

The direct attack by boiling 70% HNO_3 on

Table VII

EFFECT OF SHORT VERY-HIGH-TEMPERATURE SOLUTION TREATMENTS FOLLOWED BY AIR-COOLING

Steel	Surface Condition*	Loss in Weight, g./sq. cm., in 18 hr., After Salt-Bath Treatment† at :					
		1300° C.		1350° C.		1390° C.	
		Just up to Temperature	30 sec. at Temperature	Just up to Temperature	30 sec. at Temperature	Just up to Temperature	30 sec. at Temperature
G 19/8 Cr–Ni–Ti ...	*a*	0·0009	0·0009	0·0008	0·0009	0·0009	0·0019
	b	0·0008	0·0009	0·0008	0·0009	0·0009	0·0125
	c	0·0010	0·0010	0·0011	0·0018	0·0010	0·0704
I 18/10 Cr–Ni–Nb ...	*a*	0·0008	0·0008	0·0008	0·0009	0·0009	0·0009
	b	0·0008	0·0008	0·0008	0·0008	0·0008	0·0008
	c	0·0005	0·0005	0·0005	0·0005	0·0005	0·0005
J 18/11 Cr–Ni–Ti ...	*a*	0·0008	0·0007	0·0009	0·0006	0·0008	0·0009
	b	0·0008	0·0009	0·0009	0·0008	0·0008	0·0039
	c	0·0006	0·0007	0·0004	0·0004	0·0007	0·0560

* (*a*) Emeried ; (*b*) re-emeried after test (*a*) ; (*c*) as tested in (*b*), without re-emerying
† The time to reach temperature was of the order of ½ min.

precipitated grain-boundary carbides appears to be slow, and is not a primary cause of intergranular failure. Massive carbides in unstabilized 18/10 Cr–Ni steel were lost mainly by undermining and dislodgement, in a manner similar to the loss of the δ-phase material from the duplex titanium-stabilized steels. The most damaging attack is produced by an intergranular channelling action, and it was found that nitric acid cut much wider channels than the sulphuric-acid/copper-sulphate solution, also in conditions which favoured attack by the latter solution, the penetrating action of the nitric acid was relatively slow. On the other hand, treatments which produced practical immunity to sulphuric acid gave a much smaller reduction of the nitric acid attack.

It is concluded that carbide stabilization by titanium is less effective than by niobium. The difference is not significant under most service conditions, but with concentrated nitric acid at high temperatures niobium-stabilized steels should be used. Although not immune from intercrystalline attack in the acid under all conditions of heat-treatment, niobium steels containing 18% of Cr, 8–13% of Ni, and a 10/1 Nb/C ratio, should be free from the adverse effects of welding, including the double heat-treatment introduced during the application of sealing welds.

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Distribution of Hydrogen in Large Ingots and Forgings

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SYNOPSIS

The distribution of hydrogen in several cores trepanned from large ingots and forgings has been investigated. It is shown that severe segregation occurs, and persists in finished forgings. The variation found depends upon the size of sample, being much more severe with small specimens. Re-hydrogenation experiments demonstrate that segregation is not caused by variable hydrogen solubility. Some practical implications of the results are considered.

THE importance of hydrogen in steel manufacture is now widely recognized, and in recent years a number of papers have appeared which deal with methods of hydrogen determination in both liquid and solid steel and also with defects such as hair-line cracks, fish-eyes, and snow-flakes, which may, in part at least, be attributed to the presence of hydrogen. Some papers have also dealt with the effect of hydrogen upon the mechanical properties of steel, showing the main result of the presence of hydrogen to be loss of ductility. This effect may be of considerable practical importance when testing specimens taken from the interior of large forgings, where the size factor prevents the rapid loss of hydrogen by diffusion normally occurring in steel products of small cross-section.

Since investigations into the distribution of hydrogen in ingots and forgings[1] have been confined mainly to relatively small masses of metal, for economic reasons, it is thought that the present results referring to large ingots and forgings made by the acid open-hearth process may be of general interest.

Results are given for cores taken from two ingots trepanned after annealing, an ingot cogged before trepanning, and three cores taken from forgings and one from a forged discard. The analyses of the various steels are collected in Table I.

METHOD OF HYDROGEN DETERMINATION

Specimens were heated in a special vacuum furnace at 650° C., the gas evolved being subsequently analysed for hydrogen. The exact design of the apparatus varied with the size of sample. For small cylindrical samples, $\frac{1}{2}$ in. dia. × $\frac{1}{2}$ in. long, a modification of the apparatus first described by Newell[2] was used. It incorporates a unit for hydrogen analysis that depends upon diffusion through a heated palladium tube, as described recently by the present authors.[3] Cylindrical samples 3 in. long × $\frac{3}{4}$ in. were heated in a small vacuum furnace described in the same paper. Large specimens approx. 3 in. long × 2 in. dia. were heated in a third vacuum

Manuscript received 16th April, 1951.

Dr. Sykes is Director of the Brown-Firth Research Laboratories, and Mr. Hobson is now with Messrs. Hadfields, Ltd., Sheffield.

Table I—ANALYSES OF STEELS USED IN HYDROGEN INVESTIGATIONS OF LARGE INGOTS AND FORGINGS

Steel	Type	Analyses, %								
		C	Si	Mn	S	P	Ni	Cr	Mo	V
A	0·25% C	0·25	0·25	0·77	0·038	0·034	0·11	tr.	...	...
B	0·22% C	0·22	0·25	0·59	0·045	0·037	0·08	0·15	...	...
C	0·22% C	0·22	0·21	0·61	0·035	0·033	0·14	0·20	...	...
D	0·51% C–Cr	0·51	0·30	0·79	0·034	0·029	0·19	0·48	...	...
E	1¾% Ni	0·38	0·22	0·73	0·033	0·025	1·69	0·17	...	...
F	2¼% Ni–Cr–Mo	0·24	0·24	0·50	0·022	0·020	2·34	0·40	0·40	...
G	2½% Ni–Cr–V	0·41	0·26	0·79	0·021	0·020	2·38	0·15	...	0·11

furnace, described by Wells and Barraclough,[4] and the gas, after removal, was analysed by normal methods using aqueous reagents in a miniature constant-pressure-type gas-analysis apparatus.

In all cases the results were obtained as rapidly as possible after trepanning. The cores were usually cut into suitable lengths and kept in an insulated box that contained solid carbon dioxide at a temperature of −78° C., until they were withdrawn for machining of the test specimens. During machining, care was taken to avoid heating the sample by excessive cutting rates. Coolant was omitted when taking the final cut. Hydrogen determinations were carried out immediately after machining, so that the loss of hydrogen by diffusion was small.

PROCEDURE AND RESULTS

Cores from Large Unforged Ingots

0·25% *Carbon Steel A* (105-*ton Ingot*)—The ingot was an 80-in. octagon with a chill length of approx. 130 in. On stripping, it was given an annealing treatment and after 12 weeks at room temperature a core of 20½ in. dia. was removed by trepanning. A smaller core of 2½ in. dia. was trepanned from the larger core 11 days later.

The small core gave 29 samples 4 in. long, from each of which a 3 in. × ¾ in. dia. specimen was turned for hydrogen determination. The results are shown in Fig. 1. Several specimens were porous, although samples were turned off-centre where this was necessary to avoid shrinkage defects present in the core pieces, and the completion of the hydrogen determinations was prevented by the release, on vacuum heating, of large volumes of water, carbon monoxide, and hydrocarbons. All attempts to dry the specimens failed; this was probably the effect of internal rusting caused by the cutting oil used in the trepanning operation, followed by decomposition of the hydrated ferric oxide and cutting oil on heating. Risk of failure from this cause is always present when preparing hydrogen samples from large ingot cores.

The liquid steel used to make the ingot was found, by the modified notched pencil-mould method,[4] to contain 4·4 ml. hydrogen/100 g. in the ladle sample. Considerable loss had occurred during freezing, annealing, and machining of the ingot as the mean value of the core tests was 1·73 ml./100 g. The diagram shows that the hydrogen content of two specimens at opposite ends of the ingot exceeded that of the liquid steel, and there must have been considerable hydrogen segregation in the ingot after solidification. The segregation had persisted, for in several places two-fold differences in hydrogen content occur between adjacent specimens each weighing approx. 200 g.

0·22% *Carbon Steel B* (95-*ton Ingot*)—This ingot was a 74-in. octagon with a chill length of approx. 138 in. The ingot was annealed and a 20½-in. dia. core was removed 16 days after casting. A 2¾-in. dia. core was taken from the larger core after a further 13 days. To avoid cracks as found in the previous ingot, cylinders 2 in. long were cut from 24 positions spaced along the core, and were then turned down until they were ½ × ½ in. dia. These specimens were sound.

The results obtained are shown in Fig. 2. The hydrogen contents covered the extremely wide range of values from 0·9 to 10·2 ml./100 g., with a mean

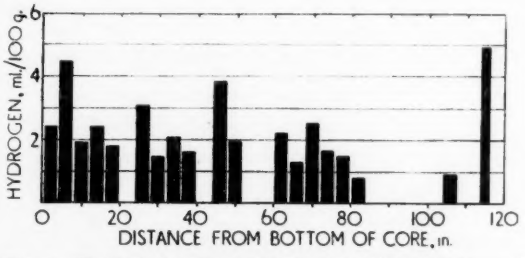

Fig. 1—Hydrogen content of test pieces from trepanned core of 0·25% C steel *A* (105-ton ingot). The unfilled sites represent specimens upon which the hydrogen results were not obtained, and the spaces between results are proportional to the material discarded in preparation of test pieces

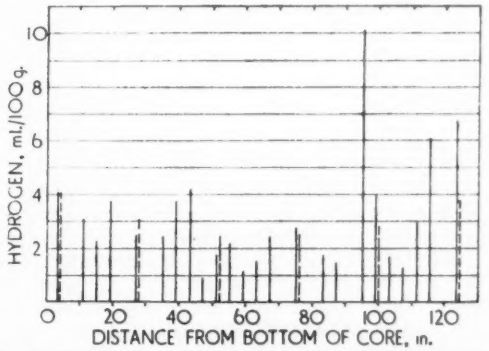

Fig. 2—Hydrogen content of test pieces from trepanned core of 0·22% C steel *B* (95-ton ingot)

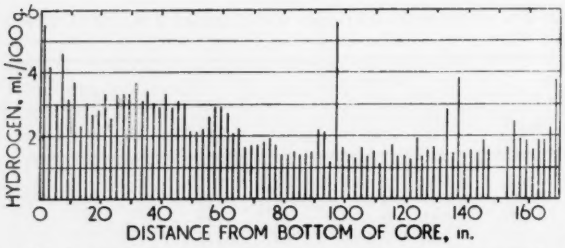

Fig. 3—Hydrogen content of test pieces from trepanned core of 0·22% C steel *C* (190-ton ingot), after cogging

value for the core of 3·2 ml. Hydrogen determinations were not made on the liquid steel of this cast, but experience indicates that 4·0–4·5 ml. would have been a reasonable estimate and the upper limit would certainly not have exceeded 6·0 ml. Thus, approximately one quarter of the hydrogen was lost by diffusion and the remainder was severely segregated. The results near the bottom and top of the ingot apparently represent metal that was cooling relatively rapidly whereas the maximum segregation was associated with the upper centre of the ingot, presumably the last to freeze.

The broken lines in Fig. 2 indicate the hydrogen content of samples taken in a similar manner from corresponding positions 7 in. from the axis of the ingot. They follow the same trend as the main results, but are insufficient to show conclusive evidence for or against segregation.

Core from Partially Forged Ingot

0·22% *Carbon Steel C* (190-*ton Ingot*)—The original ingot was a 92-in. octagon with a chill length of approx. 180 in. It was cogged to 89 in. dia. and then annealed. A core piece of 20½ in. dia. was trepanned out four weeks after casting and a smaller core of 2⅞ in. dia. was taken from the larger core after a further 12 days.

In view of the segregation found previously, hydrogen determinations were made at 2-in. intervals. The core was cut into 2-in. pieces and samples ½ in. × ½ in. dia. were machined from the centre of each piece. The hydrogen results are shown in Fig. 3.

The hydrogen values were again very erratic, with values above the general level at each end of the core piece. The main trend of the results was a fall from the bottom to the middle of the ingot, followed by a slow rise towards the top. The values fluctuated rapidly at three places in the upper ingot, adjacent samples showing as much as a five-fold difference. The mean value for the whole core was 2·2 ml./100 g. The actual value for the liquid steel is not available but the usual value for this type of steel when liquid is approximately double this.

Cores from Finished Forgings

Forging from 0·51% *Carbon–Chromium Steel D*—The original ingot, weighing approx. 60 tons, was used to make two forgings, the lower being a pinion shaft with two barrels, each of about 38 in. dia. The finished forging was trepanned and a core piece 26 in. × 1 in. dia. was obtained from a position within the upper barrel, corresponding to a position approximately one-third of the way up the chill portion of the ingot. Approximately four months elapsed between casting and trepanning, of which a fortnight was occupied by forging and heat-treatment.

The core piece was machined to give seven 3 in. × ¾ in. dia. hydrogen samples. The hydrogen contents obtained on vacuum heating were : Sample *A* 0·45 ; *B* 0·31 ; *C* 0·24 ; *D* 0·30 ; *E* 0·19 ; *F* 0·18 ; *G* 0·12 ml./100 g.

Analysis of the liquid steel from the ladle at the conclusion of casting showed the presence of 3·5 ml. hydrogen/100 g. In this forging, the major portion of the hydrogen had been lost by diffusion by the time machining had been completed.

Forging from 1¾% *Nickel Steel E*—An ingot weighing about 48 tons was used in the production of a cylinder forging approx. 96 in. long and of 48 to 54 in. dia. When, 15 weeks after casting, forging and heat-treatment were complete, a 14-in. dia. core was removed by trepanning and a smaller core, 96 in. long × 2½ in. dia., was taken from it ten days later. The small core was cut into 2-in. lengths, each turned to give a ½ in. × ½ in. dia. hydrogen sample.

The hydrogen results are shown in Fig. 4, and cover the range 1·4 to 5·0 ml./100 g. with a mean value of 2·6 ml.

The peak values shown on the graph are probably at least equal to the hydrogen content of the liquid steel, although hydrogen results are not available for this cast. Considerable hydrogen segregation was present in the core, particularly in the zone just above the centre, and diffusion losses may have been less than half the original hydrogen content.

Forging from 2¼% *Nickel–Chromium–Molybdenum Steel F, Radial Section*—In this investigation a specimen was cut from a diameter of a large discard from a forging. The original ingot weighed approx. 80 tons, and the steel contained 3·5 ml. hydrogen/100 g. when sampled from the ladle. The discard, which included a cylindrical portion 61 in. long × 44 in. dia., received a similar heat-treatment to that given to the parent forging.

A disc was machined from the cylinder about one quarter of the way along it ; this would correspond to a point about 24 in. below the top of the 130-in. chill of the original ingot. A bar 2 in. × 2 in. × 44 in. was then cut from the disc along a diameter, and this was cut into 3-in. lengths for hydrogen determination. A 6-in. piece from one end of the bar was turned down to ½ in. dia. and provided 11 cylinders of ½ in. × ½ in. This enabled conditions near the surface of the forging to be examined.

The results of the hydrogen analyses are shown in

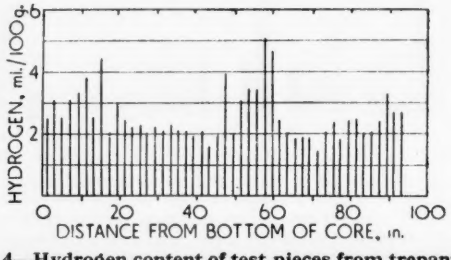

Fig. 4—Hydrogen content of test pieces from trepanned core of a forging of 1¾% Ni steel *E*

Fig. 5. The general hydrogen level is highest at the centre of the forging, and, as expected, is lower towards the outer faces. However, the results do not lie on a smooth curve and even between the 12 large main samples, the fluctuations are quite marked. Rapid changes in hydrogen content are found between the 11 small specimens and similar variations throughout the diameter were probably masked by the size of the large samples. The hydrogen content falls to a very low value near the surface of the forging and there is no evidence of a barrier or skin effect preventing loss of hydrogen to the atmosphere. The maximum hydrogen value for the large samples at the centre of the section is 2·4 ml./100 g., *i.e.*, two-thirds of the liquid steel value. The mean value of 1·15 ml. for the whole bar is about one-third of the original total.

Hydrogen distribution across the forging followed the expected trends only in a very general manner and considerable segregation of hydrogen occurred laterally as well as longitudinally.

Rehydrogenation Experiments

2½% *Nickel–Chromium–Vanadium Steel G*—In these experiments, a core was trepanned from a forging and hydrogen determined in the normal way. The test pieces were then saturated with hydrogen by heating in a high-pressure hydrogen atmosphere, and quenched ; the dissolved hydrogen was then determined. The apparatus used for hydrogenation has already been described by the authors.[3]

The core used for the experiment was trepanned from the centre of the barrel of a rotor shaft 26 ft. long with a barrel dia. of 35¼ in. The hydrogen content of the liquid steel used to make the 55-ton ingot for the shaft was 3·8 ml./100 g. in the ladle sample.

The trepanning operation was carried out on the heat-treated and rough-machined forging ten weeks after casting. The hydrogen samples consisted of two pieces 12 in. × 1⅛ in. dia. separated originally by a 24-in. length used for mechanical tests. They were machined to give seven cylinders 2¾ in. × ¾ in. dia. and six ½ in. × ½ in.

The hydrogen results are shown in Fig. 6. Considerable segregation was present, the values ranging from 1·5 to 3·6 ml./100 g. on the large 160-g. samples and from 1·7 to 5·0 ml. on the small 12-g. cylinders. The mean value for the latter was 2·5 ml./100 g., indicated by the horizontal broken line on the figure. The overall mean value was 2·1 ml./100 g. Segregation occurring at the axis of finished forgings, and also the ' average ' effect obtained by the use of larger specimens, are illustrated. Segregation is both local and persistent in the 12-g. samples ; one of them had

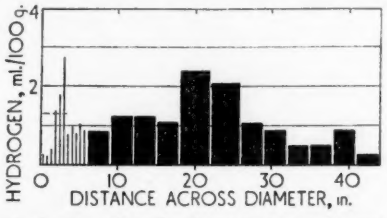

Fig. 5—Hydrogen distribution across a diameter of a forging of 2¼% Ni–Cr–Mo steel *F*

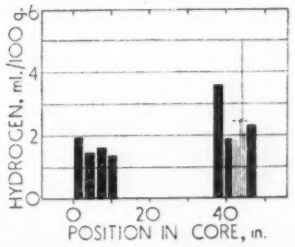

Fig. 6—Hydrogen content of test pieces from trepanned core of a forging of 2½% Ni–Cr–V steel *G*. Some of these test pieces were used in the re-hydrogenation experiments described in the text

a hydrogen content 30% greater than the original liquid steel. A 160-g. sample retained 95% of the original hydrogen.

To show that the erratic nature of the hydrogen results was not caused by variation of solubility in the forged steel, adjacent specimens showing severe segregation were heated in hydrogen under a pressure of 225 lb./sq. in. at 600° C. for 2 hr. The samples were quenched whilst under pressure and their hydrogen contents determined, with results as follows :

Sample	Hydrogen, ml./100 g. As received	After Impregnation
2	1·47	4·16, 4·20
5	3·63	4·39
6	1·82	4·33, 4·45, 4·34

They show that, although the original hydrogen contents varied by more than two to one, on impregnation the variation was only 7% for six independent results on three different specimens. Thus the original fluctuations must have been caused by hydrogen segregation rather than by large variations in the true solubility of hydrogen.

DISCUSSION

Although it is generally agreed that hydrogen is a major factor in hair-line crack formation, it has never been possible to prove any strict quantitative correlation. Sykes, Burton and Gegg[1] found no such relation, nor did the present authors, when using billets from 20 to 50 in. dia. The contents of small core test pieces trepanned from the centre of the billets varied considerably from billet to billet, but both the spread and the average value were very similar for both cracked and uncracked billets. Where sufficient core material was available for check analyses the variations obtained were much greater than the probable experimental error.

The hydrogen values for small pieces cut from large forgings apparently vary so much that any individual result is quite valueless. It was to verify this that the present work was carried out.

The results obtained show that large spatial variations in hydrogen content occur in a large forging and that the degree of variation increases as the size of the sample decreases.

The hydrogen content of the liquid steel used in the ingots and forgings examined was not likely to exceed 4·5 ml./100 g. but values considerably higher than this have been recorded in certain of the specimens. The spatial variation in hydrogen content is such that a limited number of hydrogen

determinations will not be a reliable guide either to the average hydrogen content, or to the proportion of hydrogen eliminated by heat-treatment, which is unlikely to be greater than a half to three-quarters.

It is unlikely that local segregation can occur in the liquid steel, although some, on a 'macro' scale, may occur during solidification, because of the discontinuity in solubility. We previously drew attention to the possibility that the hydrogen content might increase progressively from the bottom to the top of the ingot,[1] but the core tests showed no definite trend in this direction. This effect either does not occur or is eliminated by the diffusion in the subsequent heat-treatment processes.

If the hydrogen is uniformly distributed on a 'micro' scale when the steel solidifies, why should local segregation be found at room temperature? An explanation from the pressure theory assumes that the steel contains minute traces of porosity. The relationship between solubility S in ml./ml. and pressure P in mm. is given by the following equation:

$$S = 0{\cdot}215\, P^{\frac{1}{2}} \exp.(-3650/T),$$

where T is the temperature in °K.

Assume that on solidification the hydrogen content is uniformly distributed and equal to 4 ml./100 g., *i.e.*, $S = 0{\cdot}31$ approx. Now consider a cylindrical test piece, volume 2 ml., in the centre of a forging, with one half perfectly sound and the other containing voids equal in total volume to 10^{-5} ml.

If the specimen is cooled to 627° C., *i.e.*, 900° K. and held at this temperature, without diffusion from the outer surfaces, until equilibrium is reached between the voids and solid material, then the total gas = (dissolved gas) + (gas in voids), that is:

$$\begin{aligned} 2 \times 0{\cdot}31 &= 2S_1 + \frac{1}{10^5} \cdot \frac{P_1}{760} \cdot \frac{273}{900} \\ &= 2S_1 + \frac{273}{684 \times 10^5} \cdot \left(\frac{S_1 \cdot e^{4{\cdot}06}}{0{\cdot}215}\right)^2 \\ &= 2S_1 + \frac{273 \times 7{\cdot}17 \times 10^4}{684 \times 10^5} \cdot S_1^2 \\ 0{\cdot}62 &= 2S_1 + 2{\cdot}86 \times 10^{-4}\, S_1^2 \end{aligned}$$

where S_1 and P_1 are the equilibrium solubility and pressure respectively. To satisfy this S_1 must be less than 0·31, and hence the proportion of hydrogen in the cavities must be very small; it is:

$$\begin{aligned} [2{\cdot}86 \times 10^{-4} S_1^2]/2S_1 &= 1{\cdot}43 \times 10^{-4} S_1 \\ &< 0{\cdot}44 \times 10^{-4} \\ &< 4{\cdot}4 \times 10^{-3}\,\%. \end{aligned}$$

When equilibrium has been achieved, the gas equation at room temperature, say 0° C., becomes:

$$\begin{aligned} 0{\cdot}62 &= 2S_2 + \frac{1}{10^5} \cdot \frac{P_2}{760} \\ &= 2S_2 + \frac{1}{10^5} \cdot \frac{1}{760} \cdot \left(\frac{S_2\, e^{13{\cdot}37}}{0{\cdot}215}\right)^2 \\ &= 2S_2 + \frac{9{\cdot}04 \times 10^{12}}{7{\cdot}6 \times 10^7}\, S_2^2 \\ &= 2S_2 + 1{\cdot}19 \times 10^5\, S_2^2 \end{aligned}$$

For this equation $S_2 \simeq 2{\cdot}28 \times 10^{-3}$ and the S_2^2 term is very large compared with the S_2 term.

The amount of hydrogen dissolved in the steel is therefore $2 \times 2{\cdot}28 \times 10^{-3} = 4{\cdot}56 \times 10^{-3}$ ml., which is approximately equivalent to 0·03 ml./100 g.

Thus, although the hydrogen content of the two halves of a specimen cut at 627° C. would be almost the same, for a specimen cut at 0° C. the contents of the sound half and the half containing 1 part in 10^5 of cavities, would be 0·03 and 7·97 ml./100 g. respectively. For a similar calculation, assuming 1 in 10^9 cavities, the hydrogen contents would be 2·0 and 6·0 ml./100 g. respectively at 0° C.

These calculations agree with the results obtained from the hydrogenation experiments. In the specimens taken from the forging, any cavities would contain hydrogen at a very high pressure, and consequently the hydrogen content found in any one specimen would depend primarily on the amount of cavity present. In the specimens artificially impregnated, the pressure is small and the amount of hydrogen in the cavities negligible.

The extrapolation to room temperature of the solubility–pressure relationship is of doubtful reliability but the very high value of the resulting pressures leaves little doubt of the general trend. Similarly, the introduction of cavities of magnitude 1 part in 10^5–10^9 is unlikely to be verified experimentally by any form of density determination. Nevertheless, the authors believe that segregation into minute cavities probably causes the wide variations in hydrogen content reported in this paper.

This is confirmed by occasional hydrogen test pieces cut from forgings that show very high hydrogen values ~ 20 ml./100 g. Density determinations permit the volume of the cavities contained by such specimens to be calculated, and in certain cases, cavity pressures as high as 250 atm. have been obtained. Occasionally, when ingot heads are removed by necking and tupping, large gas flames under considerable pressure emerge. These are probably composed of hydrogen issuing from cavities connected to the fracture.

If it is admitted that 1 part in 10^5 of the volume of steel may consist of randomly distributed cavities, then the magnitude of the segregation of hydrogen into such cavities would prevent any correlation being found between hair-line crack formation and hydrogen content as determined at room temperature.

CONCLUSIONS

The results indicate that wide variation in hydrogen content exists in the centre of large ingots and forgings. Single determinations therefore may give a misleading impression of the average hydrogen content. As would be expected under such conditions, the smaller the specimen the more likely is the result to be in error.

Acknowledgments

The authors wish to thank the Directors of Messrs. Thos. Firth and John Brown Ltd. for permission to publish this paper. They also acknowledge the willing assistance of many colleagues in the work of preparation and analysis of the samples.

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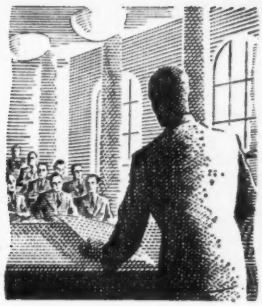
1. C. SYKES, H. H. BURTON, and C. C. GEGG: *J. Iron Steel Inst.*, 1947, vol. 156, pp. 155–180.
2. W. C. NEWELL; *Ibid.*, 1940, No. I, pp. 243P–256P.
3. J. D. HOBSON and C. SYKES: *Ibid.*, 1951, vol. 169, pp. 209–220.
4. J. E. WELLS and K. C. BARRACLOUGH: *Ibid.*, 1947, vol. 155, pp. 27–32.

DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

ANNUAL GENERAL MEETING, 1951

THE ANNUAL GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday to Friday, 30th May–1st June, 1951, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. Mr. J. R. MENZIES-WILSON, O.B.E., the Retiring President, was in the Chair at the beginning of the Meeting, his place thereafter being taken by Mr. RICHARD MATHER, the new President.

The Report of the Meeting was published in the October 1951 issue of the *Journal* (pp. 97–100).

Joint Discussion on the Papers—

THE SMIDTH AGGLOMERATING KILN : PLANT AND PRACTICE AT EAST MOORS WORKS, CARDIFF*

By W. E. Simons

SINTER MAKING AT APPLEBY-FRODINGHAM†

By G. D. Elliot and N. D. Macdonald

INVESTIGATION OF THE EFFECTS OF CONTROLLED VARIABLES ON SINTER QUALITY. Part I—Development of Experimental Sinter Plant and Preliminary Results using Northants Ore‡

By E. W. Voice, C. Lang, and P. K. Gledhill

THE SINTERING OF NORTHAMPTONSHIRE IRON ORE§

By D. W. Gillings, E. W. Voice, C. Lang, and P. K. Gledhill

Mr. **W. E. Simons** (Guest Keen Baldwins Iron and Steel Co., Ltd.) presented the first paper, Mr. **G. D. Elliot** (Appleby-Frodingham Steel Co.) the second, Mr. **C. Lang** (B.I.S.R.A.) the third, and Dr. **D. W. Gillings** (Central Research Establishment, National Coal Board) the fourth.

Dr. **T. P. Colclough,** C.B.E. (British Iron and Steel Federation): Before discussing the papers, it would be as well to indicate the magnitude of the problem confronting us. The sinter plants operating in 1949 dealt with over 4,000,000 tons of raw material and produced just over 3,000,000 tons of sinter. The plants now in process of installation and due to commence operation before the end of 1952 should raise this total to about 7,000,000 tons of ore fines, producing 5,250,000 tons of sinter (an increase of about two-thirds over the present capacity). What is the basis of this estimated tonnage ?

I am glad that Mr. Elliot emphasized the importance of removing everything below ½ in. from the ore burden. I laid down this standard a long time ago, and it is gratifying to find there is no need to deviate from this figure. The second point to emerge from these papers is that for the first time a standard for sinter is suggested.

The first rotary kiln I saw in this country was in the old Works at the Clyde Ironworks ; it was fired with blast-furnace gas for the nodulizing of iron ore. Another kiln was working in Luxembourg, operating entirely on flue dust.

Mr. Simons has under-emphasized the difficulties experienced in operating the Smidth kiln at Cardiff. Although the kiln does perform the function for which it was designed, and is able to handle a variety of raw materials, the sinter produced is not of the best quality. A comparison of the capital costs with those of other methods of sintering is not available, as no new sintering plants have been erected in this country in the last ten years.

In regard to the paper by Voice, Lang, and Gledhill,

* *J. Iron Steel Inst.*, 1951, vol. 167, Jan., pp. 1–8.
† *Ibid.*, Mar., pp. 261–272.
‡ *Ibid.*, Apr., pp. 393–399.
§ *Ibid.*, pp. 400–439.

it had long been recognized that an experimental unit was necessary ; in earlier years, samples of different ores had to be tested on the experimental units in Germany. The B.I.S.R.A. team should concentrate first on perfecting their experimental unit with all the controls and meters necessary for fundamental investigations. Later, each of the large makers of sinter in this country should have its own experimental unit for investigating which blend of its own materials will give optimum results.

With reference to the authors' conclusion (3), it is difficult to understand why the carbon in the flue dust should not be so effective as the carbon in the coke. This may be caused by inefficient mixing or incomplete weathering of the flue dust before it is used—the tremendous difficulty in wetting this material to obtain a uniform mixture is well known.

In connection with 'return fines,' on p. 269 of the paper by Elliot and Macdonald it is stated that "if return fines were reduced to zero, sinter quality would be little affected" ; on the same page it is also stated that "there were insufficient return fines to maintain sinter quality." Again, on p. 413 of the paper by the B.I.S.R.A. team, the authors state that there is no direct relation between dust index and the content of return fines, over the range 6–28%, whereas Fig. 7*e* of the paper by Voice, Lang, and Gledhill shows that there was a definite improvement in dust index up to about 18% of return fines, with very little subsequent change. Could these authors please clarify the apparent discrepancies ?

The papers agree that increased suction decreased the sintering time. Is there any relation between sinter quality and the sintering time ? This factor would have a marked bearing on plant design and speed of operation, and an optimum sintering time would determine the length and speed of the sinter strand. Since the cost of the suction is the largest item in the operating expenditure, optimum time and optimum suction are the two main items of operating costs.

In the paper by Voice, Lang, and Gledhill, Fig. 11 indicates that the air flow through a mixture of ore increases as the moisture content rises to 18%, and then diminishes with further increase of moisture content. The sintering time follows the inverse path (Fig. 10), but no reason for this is given. I suggest that the explanation may be found by examining the bulk density of the ore mixture with varying moisture content, as in the parallel phenomenon with coal. The weight of dry coal is about 56 lb./cu. ft. ; if moisture is added, the weight per cu. ft. falls to about 48 lb. with about 7% of moisture, and then rises as the moisture content increases. This is probably what happens with ore and water in a sinter mixture, and I believe it is one of the fundamental factors of sintering.

The cause of this apparent anomaly is as follows. If the pieces of ore or coal are regarded as spheres, the closest density packing and the maximum weight per cu. ft. are given with dry coal or ore. When small quantities of water are thoroughly mixed with the dry material, the first water forms a film on the particles of coal or ore, the pieces do not sit so closely together, and the weight for a given volume decreases. With the addition of more water a point is reached at which the film of adherent moisture is the maximum that can be maintained by the surface tension, the particles are at the maximum distance apart, and the packing density and the weight per cu. ft. are at a minimum. The addition of further moisture can be achieved only by water occupying the interstitial spaces ; the weight per cu. ft. increases, and the free space for the passing of air or gas is diminished.

One fundamental fact brought out by the field tests at both Corby and Appleby-Frodingham is the vital importance of intimate mixing. The variation of particle sizes, the speed of movement, the change of direction, etc., to some extent explain the segregation of the material as it passes along. Elliot and MacDonald have rightly emphasized the inefficiency of the present mixers and the dangers that arise because the material is subject to certain falls and changes of direction.

One of the functions of the sinter plant has not been mentioned in any of the papers. The sinter machine should not only remove the fines from the ore and return them to the furnace in a suitable form, but (especially with home ores) should also remove sulphur. It would be useful to determine the effects of varying amounts of carbon, suction, and moisture, on sulphur removal.

Although the suggested improvements would give sinter greater strength and a better dust index, what effect does varying these factors have on the operation of the blast-furnace using the sinter ? How do the improvements affect sinter cost, and what are the operating and economic limits, if any, within which the sinter can be used in the burden ?

Mr. **Guy Barrett** (Follsain Wycliffe Foundries, Ltd.) : In 1907, some of us who were working certain furnaces at Ebbw Vale slop-moulded 1000 tons of fine ore on the floor and made briquettes in an old brickworks. The use of these briquettes produced a considerable improvement in quality of burden and the working of the furnace, but the cost was too great. We therefore hired a rotary furnace, to which we sent 1000 tons of Sierra Minera ore. Although this furnace gave a great deal of trouble, we did make nodules, and it was evident that we should obtain a good product if the difficulties could be overcome. However, we had still not found the solution when sintering was introduced and the Greenawalt and Dwight-Lloyd plants were developed. In 1919, I was running what was in effect a small Greenawalt plant, about 1 yd. square, on Lincolnshire and Northants ores ; mixing the two ores gave very good results, but there were considerable difficulties in maintaining regular operation. The present authors are now overcoming these difficulties.

The down-draught processes can and do remove sulphur. The extent to which this can be achieved depends on the control exercised and on the ore in use.

Sinter is a fairly regular product, compared with the ore, and will therefore give improved furnace operation, but the sintering processes are wasteful in that they return a considerable quantity of fines. If the rotary kiln can be operated successfully, it will be more suitable and more likely to give a regular product.

Mr. Simons mentioned that the product of his kiln is not so readily reducible as sinter is : I do not think it can be, in a kiln of this length, as the zone of maximum temperature is so long that a very dense product is unavoidable. If, however, the operation can be carried out in a short distance and a short time, the particles will not roll over each other for a prolonged period, and will not be consolidated, as they are when they roll over a long path. If, in addition, the controls operate quickly, the rotary kiln will give the best all-round solution of the problem of the agglomeration of ores. Such a process developed for a 60-ft. kiln was successful. Further work on this has been carried out in America since the war, and recently in France I saw a rotary kiln, of overall length 45 ft., producing excellent agglomerates from dry flue dust under perfect control. Moreover, when the normal charging elevator broke down, the dust was charged into the kiln 10 ft. from the discharge end, and the process continued for 1½ hr., by which time the product was better than before. (I do not suggest that

this could be continued indefinitely.) The run lasted 2½ days, and there was no evidence of ringing. The actual operation of agglomeration commenced and was completed in a length of about ten inches.

Mr. **E. H. Lewis** (F. L. Smidth and Co., Ltd.): Mr. Barrett mentioned that the first efforts to agglomerate were made in a cement kiln. It was very soon obvious that a cement kiln, with its approximately constant diameter, was not suitable, and the shape of Mr. Simons' kiln was designed to confine the actual agglomeration to a very short distance, for it to be within reach of a scraper.

The plant referred to at Belval has operated successfully for a number of years. There is also one at Dudelange, another at Clabecq (Belgium), and several in Eastern Europe.

It has been mentioned that one disadvantage of the rotary kiln is the difficulty of reducing the agglomerate, compared with sintering on an ordinary plant. Our reports from Luxembourg, however, are of the opposite opinion; ' during extensive comparative tests using agglomerate and sinter in the blast-furnace burden, Belval found that there was a greater saving in coke when sinter was replaced by agglomerate. Attempts have also been made there to obtain the highest possible FeO content, and the addition of 2% of coke fines to their mixture has increased the FeO from about 6% to about 35%. Although this is not so high as Mr. Simons' figure, they have no trouble at Belval from the formation of ferrous silicate, which is supposed to be difficult to reduce, and no appreciable amount of this is formed within the temperature range in which Fe_2O_3 is reduced to FeO.

The rotary kiln is able to use a wide variety of raw materials. Intimate mixing takes place automatically in the kiln, and the water content and the size of the raw materials are not important. If necessary, the materials can be fed into the kiln in the form of slurry (as with cement kilns), or they can be dry. It is considered that the rotary kiln requires rather less continuous control than does a sintering plant.

Mr. **E. W. Voice** (B.I.S.R.A.): On the whole, there is considerable agreement between the three papers on sintering. Dr. Gillings and his co-authors show that the greatest effect on sinter quality (pre-supposing that the material is well mixed) is due to the percentage of coke, whereas Elliot and Macdonald found that the greatest effect is due to the percentage of true return fines. Figure 7 of the paper by Voice, Lang, and Gledhill shows that the percentages of coke, return fines, and flue dust can independently cause the sinter strength to vary from 45 to 80, *i.e.*, from rubbish to strong, clean sinter. There is therefore complete agreement that the less ore used the better.

The work described in these papers has been limited to Northants and Lincolnshire ores. When we used fine Swedish ores on the small sinter box recently, the sinter made with 20% return fines and 10% flue dust had the same high strength when from 2% to 5% of coke was used—in contrast to the results obtained with the Northants ore. Moreover, the sinter strength was the same when between 20% and 50% of return fines was used with the Swedish ore. It must therefore be emphasized that the ore used in the tests will have a marked effect on the results obtained.

Hammer milling improved the quality in the B.I.S.R.A. trials. Elliot and Macdonald crushed the stone to $-\frac{1}{4}$ in. to reduce the size range of the raw materials, whereas we found that with fine Swedish ore the use of crushed return fines did not greatly affect the speed of sintering until the average size of the return fines was below $\frac{1}{16}$ in. As Dr. Colclough remarked, spheres of the same size will give maximum permeability; the average size can be increased without altering the permeability, but using a mixture of large and small considerably reduces permeability.

With a close size grading of $+\frac{1}{16} - \frac{1}{8}$ for all the raw materials in the Swedish mix, the sintering time was 19 min. instead of the usual 40 min. for this composition. There is undoubtedly an optimum size range, for all compositions of raw mix, for which there is maximum bed permeability, maximum rate of air flow, and fastest sintering at minimum cost per ton of sinter. This question of size is therefore important.

When we state that the carbon in the flue dust is only 60% as effective as carbon in coke, we do not suggest that the carbon does not burn fully—we do not know this—but the curves we obtained show an increase in sinter strength with increasing coke or flue-dust content. If it is assumed that the improvement is due only to the carbon content of the flue dust, then the addition of 100 units of carbon in flue dust would increase the sinter strength by the same amount as would the addition of 60 units of carbon in the form of extra coke.

Mr. **T. W. Thursfield** (Gjers Mills and Co., Ltd.): We agree with all the authors that some improvement is necessary in the revolving table and plough feeding the sinter mixture belt. We are sintering 100% Sierra Leone concentrate and are particularly interested in improving the breeze portion of the sinter mixture, as above a certain limit we get slagging and below it we get very little sinter. Also, we are using up to 62½% of sinter, so that good-quality sinter is essential. It has been found difficult to adjust the breeze feed on the ordinary rotary table, mainly owing to the varying angle of repose of the material—particularly of the purchased breeze, in which there was a vast range of moisture content and particle size. Although our breeze is screened through $\frac{3}{8}$ in., oversize pieces of material persist. We therefore introduced the Millar feeder, which (so far as we know) is used in no other sinter plant. It is not dependent on the moisture content or on the angle of repose of the material, and delivers a measured quantity regularly, without any hanging up in the bunker. Installation presented very little difficulty, but it was found necessary to fit a grid screen on the top of the bunker to remove the odd pieces of oversize breeze, which interfered with the regular feed. As the material was delivered to the mixer belt in small heaps, a belt scraper was introduced to draw back the heap tops into the hollows and spread the material on the belt. We also added additional ploughs on the mixing belt.

We are satisfied that there has been considerable improvement in our sinter quality since the control of breeze has been improved; moreover, only very slight adjustments are necessary, owing to the regular feed, and our furnace practice has improved.

Mr. **R. P. Towndrow** (Colvilles, Ltd.): Elliot and Macdonald specify a $\frac{1}{2}$-in. minimum size for the material charged into the furnace. Has this $\frac{1}{2}$-in. size a special property, or does it just happen to be the minimum size which can with certainty be screened out of the particular type of ore? The theoretical desirability of having the smallest size range in the material charged to the blast-furnace is appreciated, but the extent to which this is carried must always be balanced against the cost, and there will be considerably more fines to sinter from a $\frac{1}{2}$-in. screen than from a $\frac{1}{4}$-in. screen. Perhaps the material is too sticky to screen at $\frac{1}{4}$ in.

Elliot and Macdonald reject their earlier theory that patchy sinter was caused by segregation of coke. Nevertheless, unless the coke is the proper size it will still be ' segregated,' even if it is properly mixed. I should like

to support Mr. Elliot and other speakers who have emphasized the necessity for thorough mixing.

In regard to the effect of suction on sintering rate, it seems that there is a contradiction between the two B.I.S.R.A. papers. Voice, Lang, and Gledhill refer to the logarithmic relationship between the applied suction and sintering time, whereas in experiments carried out by Dr. Gillings and his co-authors, halving the speed of the fan and the indicated suction had no clear effect on the rate of sintering or on the sinter quality. It is difficult to understand how these two statements can be reconciled. This is an important point, because if a sinter plant runs into a condition such that it is no longer large enough to sinter all the fines, means of increasing its productive capacity must be sought, and the most attractive and probably the simplest to put into effect is to use a larger fan.

Some of the phenomena in a sintering plant seem to be analogous to those in a blast-furnace. A sinter plant, like a blast-furnace, is a machine for burning coke, and probably has a 'Rice formula' which will indicate how much coke can be burnt in it. The main question is whether our existing plants are burning as much coke as they can ; if not, they must be supplied with more air.

CORRESPONDENCE

Dr. **D. W. Gillings** (Central Research Establishment, National Coal Board) wrote : We should regard Elliot and Macdonald's work as closer to a specific problem than are our own trials. We worked on a more general basis, to describe effects and (as far as possible) their underlying causes and relative importance ; at Appleby-Frodingham it was expected that results would be applied at one plant only.

I am in particularly close agreement with their emphasis on the following points :

(i) Concepts of sinter quality and its dependence on iron content of raw material.

(ii) The non-critical nature of the ignition process, compared with the importance of properties and composition of raw materials.

(iii) The wide tolerances permissible in water content (but I would emphasize the influence of the properties of the raw materials, and the importance of clay dispersed throughout these materials).

(iv) The importance attached to feed table and mixer design.

(v) The order of size suggested for raw materials, and the importance of calcination in determining this for the type of ore. The photographs showing partial calcination and sintering of the skin of large fragments are particularly interesting.

(vi) The suggestion that critical control of distribution of suction can achieve no useful result.

(vii) The importance of sized return fines. In our trials, the most satisfactory sinter was obtained when raw materials and return sinter were crushed together to similar sizes.

(viii) The acceptance of a slagged sinter.

There is substantial agreement that control of composition of raw materials is important, although there is a considerable difference in emphasis on the important components of mixtures. At Appleby-Frodingham great importance is attached to high and controlled percentages of return sinter ; as a result of our work, we regard control of the effective carbon content of the raw materials as the necessary but sufficient measure of control. The apparent need for the high percentages of return sinter may arise from the greater chemical change which takes place in the process when using Lincolnshire ore than when using other materials. The Lincolnshire ore has a high content of calcium and other carbonates and a low content of iron. The return of substantial percentages of sinter to the process may assist in keeping control during the relatively long period of decomposition and the subsequent partial fusion of the ore. When volatile contents are lower and iron contents higher, the influence may be less marked (although during the B.I.S.R.A. trials no experiment involving a large content of return sinter was carried out).

An important point on which there is no critical discussion in the Appleby-Frodingham paper is the effect on the productive capacity of the sinter plant of the inclusion of substantial percentages of return sinter. The mixture of raw materials given on p. 270 contains 50% of previously sintered material and 8% of coke. This implies that only about 8% of the total throughput of the strand comprises freshly introduced iron. Furthermore, the percentage of coke would appear to be so high as to retard the process. Could the authors indicate what factors, if any, can ameliorate this apparent drastic reduction of plant throughput, or, if the reduction is accepted, what the nature of the saving elsewhere in the process might be ?

Four items of outstanding importance in the paper by Voice, Lang, and Gledhill, are :

(i) The equipment used is a carefully chosen section of the process stage of the full-scale plant.

(ii) Experiments can be made using constant values of all variables except one in each experiment, or a statistically planned series of experiments can be carried out to study the interaction of the variables concerned.

(iii) The agreement with results of full-scale trials is striking, particularly for the variables shown to be the most important.

(iv) The conditional presentation of conclusions relating to the effect, on the sinter quality, of coke, flue dust, and return sinter contents, reflects the difficulty we encountered in determining accurately the effect of variation of relatively small percentages of return sinter. When coke and effective carbon contents vary considerably, the possibility of detecting the influence of other variables becomes remote in plant-scale experiments.

In considering the application of experimental results to practice, my unhesitating answer to the question how money can best be spent on a sinter plant would be by preparation and mixing of the raw materials. Would there be general agreement that the next step in order of importance should be to lengthen the strand ? Should this precede the use of more fan power or of new windbox valves ? All these questions are more difficult to answer.

Mr. **J. Revie** wrote : As they so aptly state, Gillings and his co-workers are not the first to encounter difficulty in achieving positive results from statistical analysis of blast-furnace data, nor—as is shown by Bond and Sanderson's subsequent search for a suitable yardstick—have they been the last. The basic problem, that of obtaining a practical mathematically expressed index of furnace performance, has been approached from widely different aspects by Rice,* Vernon,† and Elliot,‡ but it would seem that it still remains unsolved.

Some years ago it occurred to me that a practical and satisfactory value could be obtained very simply by planimetry of the completed outlines traced by the respective marking pens on the circular 24-hr. charts

* O. R. Rice, *Trans. Amer. Inst. Min. Met. Eng.*, 1920–22, vol. 67, p. 599.

† M. A. Vernon, *J. Iron Steel Inst.*, 1933, No. I, p. 115.

‡ G. D. Elliot, *Iron Steel Inst., Spec. Rep. No.* 30, p. 108, 1944.

used for recording blast volume and blast pressure, the ratio

$$\frac{\text{Area enclosed by outline on 24-hr. blast-volume chart}}{\text{Area enclosed by outline on 24-hr. blast-pressure chart}}$$

constituting a drive index directly expressing in mathematical terms the blast-volume/blast-pressure relationship instinctively but arbitrarily evaluated every time the furnace superintendent or his assistants look at the blast-volume and blast-pressure gauges. An index determined in this manner would combine the advantages of the methods described by Rice and Elliot without the respective disadvantages of being based on spot observations of a factor which even in a smoothly operating furnace may vary materially in a few minutes, or on considerations other than that of the blast. Further advantages of an index so determined would be that (i) it would not be directly influenced by factors such as coke consumption or furnace output, which, as pointed out by Rice, are not necessarily indicative of furnace performance, (ii) it would be unaffected by incidental stoppages or delays, and (iii) being a direct mathematical expression of furnace drive—as a *performance* criterion should surely be—the index would be eminently suitable for statistical correlation studies of the effects of variables on furnace working.

It will be realized that the 24-hr. charts referred to were not designed to be used as media for the determination of a drive index, and geometrical or mathematical corrections may be required in the calculation ; these, however, would be straightforward and evident. Incidentally, planimetry of chart outlines may also be a useful method of obtaining true average values for top-gas temperature and pressure.

AUTHORS' REPLIES

Mr. **W. E. Simons** said in reply : I should like to thank Dr. Colclough for his encouraging remarks. What success has been achieved on the Cardiff agglomerating plant has been due to the hard work and loyal co-operation of all who have worked on the plant, particularly the blast-furnace engineers.

In regard to the reducibility of the agglomerate, we have always tried to obtain the highest possible content of Fe_2O_3 and not (as Mr. Lewis has remarked) of FeO, as is the practice at Belval. Mr. Barrett referred to the great length of the kiln ; this is only to give pre-preparation, the actual agglomeration taking place within the last 15 ft. The difficulties that arise when determining the length of a kiln are the variation in the carbon in the feed, and the moisture.

Mr. Thursfield's bunker discharge arrangement involves almost the same principle that we use on the agglomerating plant bunkers, the difference being that at Cardiff we do not have rollers but pressed laminar steel plates with a ratchet device, and we can dispense with the bunker gate.

Mr. **G. D. Elliot** said in reply : Dr. Colclough's reference to p. 269 rather unfairly lifts a sentence from its context. The statement that " if return fines were reduced to zero, sinter quality would be little affected " referred to practice at that time. Later, we were referring to a quite different practice arrived at in the progress of the investigation.

We fully agree with Dr. Colclough as to the importance of sulphur removal in the sinter plant. This subject was extensively investigated, and work still continues. The results show that up to 60% of ingoing sulphur can be removed. Unfortunately, harder burning reduces the degree of desulphurization.

The reference to costs is timely. Almost any improvement in sinter making will inevitably lead to an increased cost of sinter, but it must be remembered that it is the results on the blast-furnace that determine the economics of sinter making, and blast-furnace economics forbid the use of bad, cheaply made sinter. In effect, Dr. Colclough's earlier reference to removing everything below ½ in. from the ore burden defines the economic limits of sintering.

Mr. Towndrow raised the question of size grading and of the lowest acceptable particle size in the burden. As a result of experience with Frodingham and Northants ores we believe that ½ in. is the correct size of rejection for our furnace practice, and it was not the consideration of screening difficulties that led to the adoption of this figure as a standard. Acceptance of a minimum ore size for the furnace, at a level too high for good sintering, inevitably introduced crushing of the fines in the sinter plant. It is perhaps this development, more than any other, that has permitted ore preparation to take its rightful and very important place in the ironworks.

We are in complete agreement with Mr. Towndrow's remarks about " a Rice formula " for sintering plant, and believe that most sinter plants are equipped with an insufficient supply of sintering air. This problem is being investigated.

Dr. Gillings correctly pointed out that to increase return fines leads to decreasing tonnage from the machine. Again, blast-furnace economics determine the answer—efficient furnace practice based on home ores forbids the use of inferior quality sinter. We are very interested in Dr. Gillings' suggestion to lengthen the sinter strand, and believe this procedure will eventually be adopted, together with greatly increased fan power.

Mr. **C. Lang** said in reply : The importance of the mixing of the raw materials has already been mentioned, but on our experimental unit little segregation occurs. Recent experiments have shown that the size grading of the materials can also be important in sintering ; in particular, the size and quality of the return fines have a considerable effect on the sintering time.

The discrepancy between the results obtained when using increasing percentages of return fines in the full-scale trials and on our experimental unit can be attributed to the fact that the size and quality of the return fines on the plant were very variable, and it contained appreciable amounts of calcined materials. On the experimental unit, crushed sinter of controlled size was used. Other uncontrolled variables on the plant may have obscured the effect of the return fines. In reply to Dr. Colclough, the flue dust was fully weathered and uniformly mixed with other raw materials.

The effect of increased suction on sinter quality was to slightly reduce the strength and increase the dust figures, although the results obtained were rather variable and more work on this must be carried out before they can be considered definite. We agree with Mr. Towndrow that the contradiction between the two B.I.S.R.A. papers, as to the effect of increased suction, requires some explanation, but it should be realized that the results quoted from the plant are on single scattered observations, whereas those from the experimental unit were a planned series. Sulphur analyses were not carried out on this series of experiments, but recent work is including this technique.

Dr. **D. W. Gillings** said in reply : There has been extensive reference to the balance achieved between specific answers to practical problems encountered in any one practice and a more general appreciation of the basic physics and chemistry of the process as carried out under conditions of industrial everyday production. Although it can be claimed that an advance has been made in defining good conditions for any one plant, the general principles are not sufficiently understood to predict, for instance, the benefit to be obtained by

changes in practice, suggested by the analysis of present results. More information must be obtained by further laboratory, semi-scale, and production-plant experiments.

The semi-scale equipment is not a model equipment in the sense that there might be a general scaling of all dimensions to maintain constancy of conditions deduced from previous experiment or calculation. It is used essentially to carry out a carefully selected stage of the full-scale process, maintaining as many dimensions, parameters, and conditions as possible identical with the corresponding quantities and conditions on the production plant. This is also true of the equipment used successfully on similar processes such as combustion and coke manufacture, and the results obtained with the small plant are confirmed by both the nature of the experiments and the good correlation between the results for semi-scale and large-scale equipment. Experiments can thus be carried out with careful control of the more important variables, and the influence of less critical factors can be evaluated.

Many of the limitations indicated in the discussion arise from difficulties in designing similar experiments and equipment to deal with the stages of mixing, transporting the raw materials, and feeding the mixture to the strand.

Mr. Towndrow pointed out apparent anomalies in the results of the various trials to determine the effects of variations of suction applied to the windboxes. In particular, the observation that suction could be varied on the production plant with no influence on sinter quality and little influence on rate of sintering did not seem to agree with the results of the semi-scale trials, which revealed a logarithmic relation with sintering time. The reason for the disagreements is probably that, as the relation is logarithmic, a great variation of suction would be necessary to bring about a change in sinter quality. In the full-scale trials it was never possible to eliminate fluctuations of more important factors, and thus the effect of change of suction would probably be unobserved. Moreover, the semi-scale results do not refer to assessments of quality and in this instance only are not strictly comparable with the results from the production plant.

Dr. Colclough referred to the combined significance of the rate and cost of production, the cost of using or not using a given proportion of sinter, and the cost of improving the quality of the sinter. It is difficult to answer these questions on the basis of the present results. When the programme for the trials was being drawn up, it was felt that until the quality of the sinter could be improved and controlled, experiments on increasing production or evaluating costs could not yield significant results. Our paper included tabulated results of blast-furnace operation using sinter of good quality; we attempted to extend this treatment to answer the type of question asked by Dr. Colclough, but it could not be agreed what proportion of the existing information was relevant and reliable. Much work has still to be completed before a full practical result can be obtained. Dr. Colclough also referred to apparent inconsistencies in the reported influences of return fines on sinter quality. These anomalies can be partly explained by regarding the percentages of return fines used in the various experiments as falling into two ranges. If the amount of return fines is below 20% and the variations are of random origin, it is difficult to detect any relationship between these variations and those of quality in full-scale operations; the effect is less than that of the fluctuations of fuel content that accompany the fluctuating return of sinter. Under the controlled conditions of semi-scale experiment, the relative influences of fuel content and return sinter can be partly evaluated. But if the percentage of returned sinter is as high as 50%, as in the trials at Appleby-Frodingham, the conditions of the process are materially changed. A different influence of the return sinter content is then detected in the full-scale work, and the results of the semi-scale experiments show that the influence of fuel content, as a factor controlling the sinter quality, becomes modified and is to some extent replaced by the controlling and stabilizing influence of percentage of return fines. It must be remembered that the influence of high return-fines content on sinter output is very considerable.

It is important that the relative significance of factors governing the rate of production should be assessed, and further work should be carried out on these lines. Firstly, data must be made available to determine the influence of variation in the return-fines content on the rate of production. Secondly, more comprehensive figures must be derived from observations on working blast-furnaces, so that economic limits to maintenance and improvement of sinter quality are not exceeded by further elaboration of plant and control. Finally, engineering improvements based on data from the present trials must be developed as rapidly as possible.

Discussion on the Paper—

SIGNIFICANCE OF EQUILIBRIUM AND REACTION RATE IN THE BLAST-FURNACE PROCESS*

By Dr. J. B. Austin

Before presenting his paper, Dr. **Austin** (Director of Research, The United States Steel Company) showed a number of films entitled "Study of the Zone in Front of a Blast-Furnace Tuyere by Means of High-Speed Motion Pictures and Models," illustrating the work of some of his colleagues, principally that of Mr. Robert Buchanan, who took the films.

A very high speed, 2000-3000 frames/sec., was necessary to slow down the action sufficiently to take motion pictures through a tuyere to study the reactions in a blast-furnace.

The first film began with a view of the peep-sight, as modified to enable the pictures to be taken. The interior of a furnace in normal operation was then shown, illustrating the great differences in colour and in brightness of the individual particles, which are believed to be largely coke.

The film indicated that there was a circulatory motion. A model was therefore made of the section in front of the tuyere, the particles being represented by oak cubes.

* *J. Iron Steel Inst.*, 1951, vol. 167, April, pp. 358–363.

The sides of the model were glass plates, so that it was possible to show the way in which the oak blocks circulated around a void space. The cubes were packed together at the top, upheld partly by air pressure and probably partly by mechanical locking.

In several of the films a water-cooled probe was inserted for a known distance, beyond the end of the tuyere, to estimate how far it was possible to see into the furnace. The probe, which was in the furnace only for a few seconds, became coated with iron and slag in the form of extremely fine shot : the iron and slag had been blown into very small particles which could probably not be photographed. Most of the films were taken with a blast pressure of about 20 lb./sq. in. In a second film, showing a furnace in which the pressure was 10 lb./sq. in., the motion was significantly slower. A curious spongy mass appeared in the background : it was difficult to say whether this was the 'dead man' or something that had fallen in front of the tuyere zone.

Dr. **Austin,** in introducing his paper, added : It is now possible to give some quantitative data obtained from the experiments of Darken and Filer, to which reference is made in my paper. These workers determined how closely equilibrium with respect to sulphur, silicon, and manganese in slag and metal is achieved in the blast-furnace, by remelting samples of slag and metal, taken simultaneously from a commercial furnace, and by holding the melt for a long period at constant temperature. The melts were made in a covered graphite crucible suspended in a furnace through which carbon monoxide was passed ; 5 g. of slag and 6 g. of metal were used for each melt. After a predetermined time at temperature the crucible and its contents were drastically quenched and the slag and metal were analysed.

In one series of investigations, the composition of the initial slag and metal was :

Metal

0·028% S ; 1·01% Si ; 2·04% Mn ; 0·288% P

Slag

1·50% S ; 33·71% SiO_2 ; 1·11% MnO ; 0·21% FeO ; 12·79% Al_2O_3 ; 42·81% CaO ; 6·87% MgO

The temperature of the slag as it came from the blast-furnace was about 1480° C. (2700° F.), that of the metal about 1425° C. (2600° F.). Remelts were made at 1400, 1500, and 1600° C.

The change in sulphur, silicon, and manganese content with time, at three different temperatures, is shown in Figs. A, B, and C. At each of the three temperatures the sulphur equilibrium was attained rather rapidly, *i.e.*, in about 2 hr. Interference with the manganese and silica equilibria arose from volatilization ; there was a continuous loss of manganese from the system. The manganese equilibrium was, however, substantially

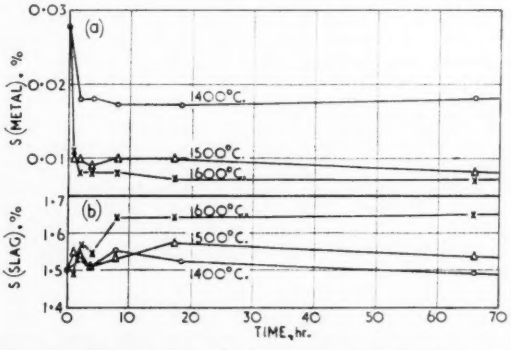


Fig. A—Change of sulphur content with time and temperature : (*a*) In metal ; (*b*) in slag

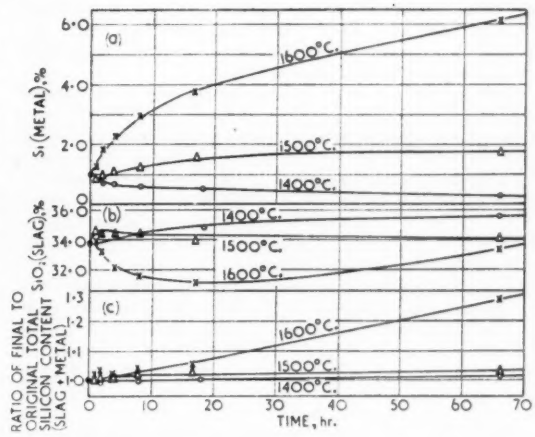


Fig. B—Change of silicon with time and temperature : (*a*) In metal ; (*b*) in slag (as SiO_2) ; (*c*) ratio of final to initial total silicon

achieved in about 10 hr. (*see* Fig. C (*c*)). The decrease in the distribution ratio at 1600° C. after 65 hr. results from a change in the silicon content of the system.

At 1600° C. there was a continuous increase in the total silicon content of metal and slag, which is attributed to volatilization of silicon from the porcelain tube of the remelt furnace. At lower temperatures, however, the silicon equilibrium requires about twice as long as does manganese.

Since the effective temperature prevailing in the hearth at the time the samples were taken is not known, it is uncertain whether the metal and slag were originally at equilibrium in the blast-furnace. Comparison of the original composition of slag and metal with the equilibrium data shows, however, that the sulphur content of the original samples corresponds to the equilibrium value at about 1300° C., whereas the manganese and silicon contents correspond to equilibrium at approx. 1400° and 1450° C. respectively. This large discrepancy indicates

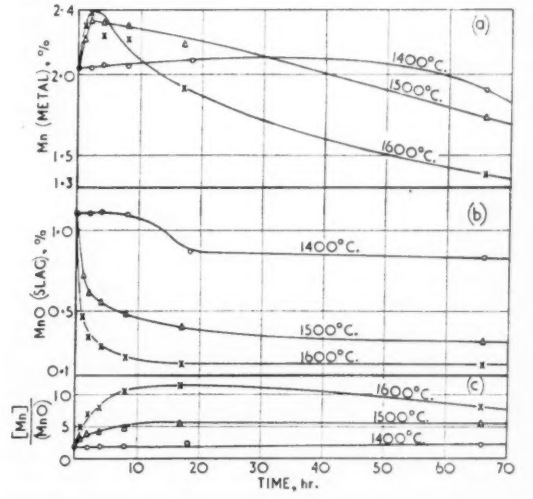


Fig. C—Change of manganese with time and temperature : (*a*) In metal ; (*b*) in slag (as MnO) ; (*c*) manganese distribution ratio

that equilibrium with respect to these three elements had not been attained in the blast-furnace and, with the possible exception of silicon, it seems unlikely that equilibrium is reached in practice.

Complete details of this investigation will be published later.

Mr. **R. A. Hacking** (Richard Thomas and Baldwins Ltd.) : In discussing the carbon requirements of the ideal process, the author assumes a temperature of 900° C., giving a carbon consumption of 1500 lb. This coincides with a CO/CO_2 ratio of 2·1/1, which is in the range achieved in full-scale practice. I should like to know why he chose that temperature.

Several of us have been pressing the argument, first put forward by Mathesius in 1915, that the coke rate can be lessened by increasing the amount of direct reduction if enough heat is available to sustain it : direct reduction becomes desirable only when the hearth heat requirements are relatively low, and there is therefore heat to spare at the critical point.

So far as American Lake-ore practice is concerned, I assume it is always true that a substantial amount of direct reduction is associated with maximum fuel economy. In British lean-ore practice we strive to cut direct reduction down to the minimum, but this may change with improvement in fuel, use of higher blast temperatures, and perhaps super-oxygenated blast.

The author concludes that many modern furnaces are operating close to equilibrium, and I would ask him, which equilibrium ? In Fig. 1, there are the three oxide curves, Fe–FeO, FeO–Fe_3O_4 and Fe_3O_4–Fe_2O_3, and the C–CO–CO_2 curve, which in my opinion may be the most significant of all. Which do we look on as the ultimate target ?

I do not share the author's complacency regarding the approach to equilibrium of the gas phase. In the best furnace practice in the world today, I think there is scope for improvement in the CO/CO_2 ratio of the exit gas. In Kinney's work* on the Illinois furnace using Lake ore and employing a characteristic **M** stockline, the mean CO/CO_2 ratio of the exit gas was about 1·7/1. The hot, high-velocity gas streams in the inwall and central zones, however, had CO/CO_2 ratios as high as 3·7/1, whilst in the cooler, slow-moving gas streams rising through the concentrations of fines in the intermediate zones, the ratio was only 1·3/1. To achieve an average ratio of 1·3/1 with the facilities available in Kinney's furnace, would involve driving rates far below the limits of practicability. We are striving to improve gas/solid contact and thermal and chemical exchange so that we can improve our CO/CO_2 ratios without sacrificing driving rate : the ultimate result may be a compromise.

The author's theoretical conclusions on the use of the super-oxygenated blast agree fairly well with results of full-scale practice. He concludes, as most of us do, that at present it is likely to be helpful only in ferro-alloy manufacture. The author believes that in ferro-manganese practice the hearth temperature is appreciably higher than in ordinary basic practice. The U.S. Bureau of Mines' determinations,† published in 1925 indicate that in ferromanganese practice, tuyere-zone slag and metal temperatures were appreciably lower than in basic practice—the endothermic hearth reactions apparently outweigh the higher coke rate and the use of maximum attainable blast temperatures.

The experience of my own company indicates that the most useful property of carbon, in addition to its refractoriness, is its conductivity. Carbon is useful only in locations within reach of effective water or other means of cooling ; the centre of the hearth floor is therefore excluded. In the well walls, however, carbon is the best material we have yet tried.

In the section on " Rate of Combustion of Carbon " (p. 362), there is a great contrast between the temperatures and flow rates obtained by Tu, Davis, and Hottel (*see* Fig. 3), and those occurring in full-scale practice. For example, the highest flow rate mentioned by these workers is 50 cm./sec., whereas the figure of 120 cu. ft./sq. in. of cross-sectional area, commonly used to fix tuyere sizes in this country, corresponds to a velocity of 288 ft./sec. at N.T.P., and of course to something much higher at working temperatures and pressures. In the tuyere zone, temperatures are usually much in excess of 1600° C., whereas the common portion of the curve in Fig. 3 lies in the surface temperature range of 700–800°C.

As each droplet of iron and slag makes its way down the bosh and through the tuyere zone, because of the very turbulent conditions, droplets in contact should approach equilibrium. That this is not so suggests a considerable amount of short circuiting and variation in composition of the individual droplets reaching the well.

Dr. **H. L. Saunders** (Imperial College of Science and Technology) : We have long realized that photography through the tuyeres could give information on what is going on inside the furnace. Three years ago we made a few still photographs through the tuyeres, but they did not give much information. We have also worked on models with the aid both of cine- and stereo-cine-photography, and during this meeting, Mr. Ward, who was responsible for the latter work, is arranging to show a film, which must be viewed through prismatic or Polaroid spectacles.

On p. 359, the author concludes that the coke rate is determined mainly by the need of carbon as a reducing agent, rather than as a fuel. This is generally true if it is assumed that equilibrium is nearly reached in the blast-furnace, but is this assumption always justified ? The author cites figures given by Kinney, and measurements reported by Wiberg and analysed by Gumz, with furnace units which by modern standards are relatively slow-working. Kinney, in addition, used a substantial proportion of fines in the burden. Both workers, therefore, used conditions that were very suitable for a close approach to equilibrium.

A similar assumption is not necessarily valid under conditions of hard driving or with a large quantity of magnetite in the burden. A wide range exists between lean and rich ores used in Britain ; Masabi and similar ores of high reducibility and good iron content are not available in this country, and equilibrium is probably less closely approached in British practice.

The coke entering the combustion zone has already been heated to a high temperature by the ascending gases, so that the top right-hand corner of Fig. 3 is of major interest. In this region the rate of combustion is governed more by the air supply than by the reaction velocity.

Generally, high combustion rates mean a rapid descent of the burden, a shorter contact time, and less complete reduction of FeO to iron ; this means more direct reduction in the hearth, with its higher heat demand. However, economic direct reduction may depend only on the carbon requirements of the reaction, and the necessary endothermic demands must be met by burning more coke.

The carbon requirements using a hematite burden with a slag volume of 15 cwt./ton and a blast temperature of about 570° C., which gives a theoretical flame temperature at the tuyeres for carbon burning to carbon monoxide of 1900° C., are given in Fig. D. For a pig

*S. P. Kinney, *Technical Paper No.* 442, 1929, U.S. Bureau of Mines.

† S. P. Kinney, *Iron Age*, 1925, vol. 116, p. 466.

iron with about 4% of carbon and 1% of silicon, a temperature difference of 30° C. may be allowed for heat transfer; this gives the equivalent difference in terms of excess available heat in the ascending gases over the heat demand of the burden for each temperature level in the furnace. Curve *P* represents the carbon required for the reduction of metalloids, *D* the carbon requirements for direct reduction between 0 and 100%, and *H* the heat requirements in terms of carbon. Curve *T* is the sum of these three. The carbon solution loss has been deliberately excluded for simplicity: its inclusion would move the curve *T* further to the top left-hand corner, although the same argument would apply.

The CO/CO_2 ratio increases with increase in direct reduction and for any given CO/CO_2 ratio the position of the lines fixing the total carbon consumption may be calculated. Under conditions of harder driving there is more direct reduction, and the coke rate goes up.

For a given carbon rate, say 16 cwt./ton, there can be a whole range of exit gas ratios between about 1·1 and 3, corresponding to different degrees of direct reduction; alternatively, if the exit gas ratio is fixed, there is an optimum carbon or coke rate corresponding to some particular direct reduction ratio. To preserve the right balance, it is necessary to adjust the driving rate to suit the ores being smelted, or to adjust the balance between the hard and soft ores in the burden. There may be other ways of reducing the coke rate, but it is essential that conditions should be those represented by the left-hand side of Fig. D.

Typical examples of reduction curves are plotted in Fig. E: the reduction of 100% Fe_2O_3 follows the top curve. A line *AB* can be drawn to divide the curves into two families. Above *AB*, the reaction is controlled by the reactants; below *AB*, diffusion rates are probably the controlling factor. If we could cut out the diffusion process completely and at the same time work at a low temperature, the CO/CO_2 ratio would improve, but the reaction rates would become very slow, particularly with normal burdens. Is the answer to be found in a partly fluidized bed and much smaller material? Is the condition partly achieved in the U.S.A. by higher blast pressures at the tuyeres?

Dr. **J. H. Chesters** (The United Steel Companies, Ltd.): It is unlikely that any fundamental work has been done on the flow of jets at such high velocities into porous beds of this type, but the general behaviour seemed reasonable in the light of other experience. We know, for example, that a simple jet in free air causes entrainment; wherever such a jet is surrounded by a container, recirculation occurs. More recent work carried out by The United Steel Companies, Ltd., has shown that the presence of a flat surface introduced beneath a jet causes the recirculation to be limited to the top surface of the jet.

One could perhaps understand the film shown by Dr. Austin by imagining a rubber balloon fitted over the tuyere tip. As this blew up under the static pressure the coke would be forced away. If the balloon were pricked, *i.e.*, air were able to escape through the interstices in the coke, the balloon would collapse leaving a large void. The air jet within this void would show recirculation, most of the flow being on the top side because of the solid bed below. The coke, being much heavier than the air, would not follow the flow pattern completely but would tend to be picked up and dragged back towards the furnace walls. If the model tells the true story the refractories must be subjected to heavy abrasion by the returning coke.

Can Dr. Austin explain the relative durability of carbon linings in the stack? When our work on such

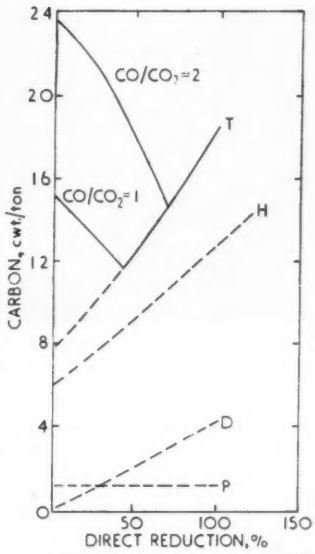


Fig. D

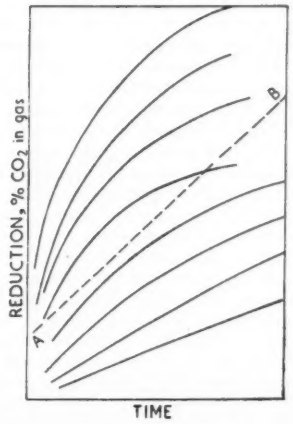


Fig. E

Fig. D—Carbon requirements in the furnace using a hematite burden

Fig. E—Typical reduction curves for Fe_2O_3

linings started two years ago it was suggested that they would inevitably burn, but the burning rate is found to be small compared with the rate at which the coke itself disappears. Is it possible that the gases passing up through the stack are so nearly in equilibrium with the coke and deposited carbon that when they strike the lining (which will normally be slightly cooler than the burden) they tend to deposit carbon rather than to pick it up. We are confident that carbon is the correct material for the hearth walls, bosh, and lower parts of the stack; an exact understanding of the equilibrium in the blast-furnace might enable us to determine more scientifically the correct material for the other sections of the furnace.

Mr. **H. D. Ward** (B.I.S.R.A.): As Dr. Saunders has said, B.I.S.R.A. has been studying tuyere photography to find the best arrangement for measuring the size of a photographed object, and for determining its position in space, despite a distance of about 8 ft. between the camera at the tuyere latch and the end of the tuyere nose.

Using a simple photograph taken with a small depth

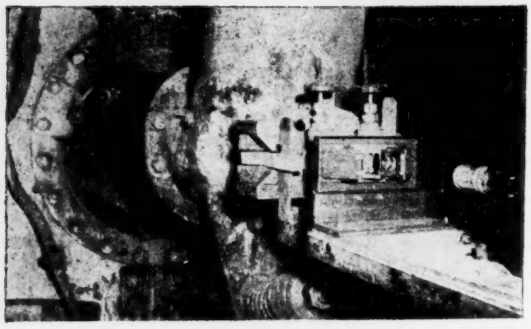


Fig. F—Design of tuyere door used for stereoscopic photography

of field, any object that is in focus would necessarily be at the predetermined focal distance and can be positioned. If the depth of field is great, the distance of the object is not known and it cannot be measured precisely. Calculation* shows that, to get a total focal depth of 5·76 in. at a distance of 10 ft., a 5-in. dia. lens must be used. A viewing hole of this size in the tuyere door is not practical, because of the danger arising should slag enter the tuyere, Stereoscopic photography was therefore examined as an alternative method.

For the stereoscopic system, a tuyere door with two viewing holes, with centres 4½ in. apart, was designed (*see* Fig. F). The distance between the viewing holes is almost twice the human interocular distance, and gives almost twice the normal relief when pictures taken in this way are viewed stereoscopically. The normal blue spectacle glass is replaced by a ⅛-in. quartz disc, mounted in a brass housing, which provides a perfect seal from blast leaks. The brass mounts are screwed to the free side of two 1¼-in. dia. gate valves, which are attached to the viewing holes to facilitate removal of the mounts in order to clean the quartz windows. In front of the valves is the stereoscopic picture splitting unit, consisting of two surface-silvered mirrors and a 90° silvered prism. The camera is positioned so that the vertical end of the prism divides the film gate of the camera into two equal parts, and thus takes two simultaneous pictures side by side (*see* Fig. G).

The picture shown in Fig. G is a print from one frame of a 16-mm. film taken with a cine camera at 3000 frames/sec. At the time of exposure, the furnace was operating at a greater wind volume than normal. The increased blast has partially decreased the amount of material moving in front of the tuyere and has revealed a mass which remains stationary throughout the duration of the film.

From such pictures, it is possible to calculate the distance of each particle from the nose of the tuyere. For example, the solid mass in Fig. G is 2·4 ft. ± 1 in. from the end of the nose. Similarly, by examining consecutive frames of the film, the velocity of particles and their rate of reduction in size may be obtained. The system uses a small lens, and a maximum depth of field is obtained. The full depth of tuyere zone is thus in focus on one frame and the dimensions of any lump can be measured.

The cine films can be viewed stereoscopically in two ways. In the first method the two images can be projected on to the screen and viewed with prismatic spectacles: the stereoscopic effect is good after the eyes have had a little time to accustom themselves to this new conception, but observers must be at the one correct distance from the screen and straight in front of it. In the second method, the films are projected through a unit similar to the taking picture-splitter; the splitter is adjusted so that the two pictures almost coincide upon the screen. The two beams from the unit are polarized, one vertically and one horizontally. For viewing, a pair of spectacles similarly polarized is worn; thus each eye sees only one picture, and the stereoscopic effect is immediately obtained. A large number of people can view the film at the same time. Unfortunately, the illumination is reduced to about 50% by the polarization, but this may be overcome by the use of a powerful source of illumination in the projector.

(A projector was set up in the Library of the Institute, and on the Thursday, the stereoscopic films referred to were shown, using the two methods of viewing which Mr. Ward had described.)

Mr. **R. P. Towndrow** (Colvilles, Ltd.): The author mentions reducing the sulphur from 0·03% to 0·02%, but the average blast-furnace manager in Britain would be very pleased if he could get the sulphur down to 0·03%. The slag-sulphur/metal-sulphur ratios of casts, made under similar conditions of slag basicity, temperature, smoothness of furnace operation, and other factors influencing desulphurization, vary considerably. In the blast-furnace we are not dealing with a simple equilibrium between a bath of iron and a bath of slag; other factors, particularly the conditions of oxidation or reduction existing immediately in front of the tuyeres, influence the equilibrium.

We should like more information on the reactions occurring during the approach to equilibrium. We practical men are not satisfied that equilibrium is nearly approached: we should like to know why it is not, and what we can do to attain it.

In this country, some of us work with burdens which chemically should make it possible to operate with some beneficial direct reduction. We work with a fairly low slag volume and presumably a fairly low hearth heat requirement. The circumstances which give rise to these low slag volumes exist, however, because large quantities of magnetite ores are used. These are difficult to reduce and considerable direct reduction occurs; thus although a coke consumption only slightly greater than 15–16 cwt./short ton is achieved, the CO/CO_2 ratio is seldom below 2, and is often greater than 2·5.

If we can obtain an even greater reduction in coke rate by lowering the CO/CO_2 ratio from 2·5 to 2·1 extremely low coke rates would be obtained. I am doubtful about some of the suggested methods of obtaining these coke rates, but with some of the burdens used the speed with which it is possible to operate the furnace is restricted if the CO/CO_2 ratio is to be kept within desirable limits.

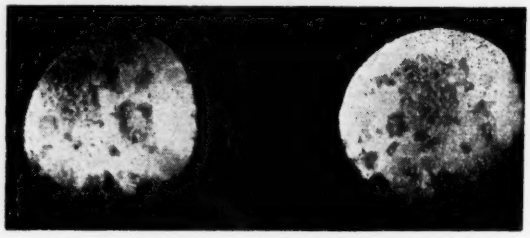


Fig. G—Print from one frame of a 16-mm. film showing two simultaneous pictures side by side

* Total range in focus is $2d^2/10^3S$, where d is the distance, in inches, from the camera to the object, and S is the iris diameter in inches

Dr. **T. P. Colclough** (British Iron and Steel Federation): In blast-furnace operation there is an equilibrium condition for each temperature. In the last twenty years we have done much to approach equilibrium at 650° C. For this temperature, the calculated CO/CO_2 ratio is 1 ; in practice 1·2 may be assumed. In a paper presented in 1950,* I indicated the coke consumption that should be attained in a blast-furnace operating with this equilibrium value.

The air blown in at the tuyeres must combine with the carbon in the coke to form carbon monoxide and nitrogen ; no other gaseous constituent can be present in the part of the blast-furnace in which the temperature exceeds 1000° C. This CO can only be converted into a CO/CO_2 ratio of 1/1 in the stack by supplying the uprising stream of gas with oxygen, and this oxygen can come only from the iron oxide in the ore. Before it is possible to attain equilibrium, therefore, the operator must calculate the required amount of oxygen, in the form of ore.

I emphasize this because, at present, in a field test on a blast-furnace the size of the coke or the grading of the ore, or some other factor is altered, the ratio of ore/coke is not deliberately changed. A lower coke rate cannot possibly be achieved unless more ore per pound of coke is charged.

In the direct reduction zone the carbon is burned to CO by the oxygen from the blast or by the oxygen available from the direct reduction of the ore. When operating a burden comprising ores, some of which are subject to direct reduction and some to indirect reduction, the different types of ore must be deliberately proportioned to attain the desired CO/CO_2 ratio. The ores that are subject to direct reduction can form only CO and the proportion of ore capable of indirect reduction must be sufficient to supply the oxygen required to change the CO formed by direct reduction, and the CO formed by the blast, to the desired ratio. The optimum ratio of direct reduction to indirect reduction ores in the burden can thus be calculated.

Only when the correct proportions of the two different types of ore are distributed to the individual blast-furnace plants will it be possible to obtain optimum conditions throughout the country.

Dr. **F. D. Richardson** (Nuffield Research Group in Extraction Metallurgy, Royal School of Mines): Mr. Jeffes and I† have made a thermodynamic study of the chemistry of the blast-furnace. On thermodynamic grounds, we concluded that, in normal practice, slag and metal were well out of equilibrium with respect to sulphur —the metal carrying far too much. We also concluded that the metal probably carried less silicon and possibly less manganese, than the equilibrium value. Our view concerning sulphur was at the time supported by the laboratory work of Hatch and Chipman,‡ and is now borne out by the work Dr. Austin has just reported. We assumed that the temperature was 1480° C., and that slag and metal were both in equilibrium with carbon, but this latter assumption was questioned when we presented our paper : I would like to know the views of Dr. Filer and Dr. Darken on this matter.

The argument that slag and metal are out of equilibrium with respect to carbon is based on FeO contents of 0·5–1% for blast-furnace slags. At equilibrium the contents should be about 0·03% corresponding to an activity of approx. 0·001. The higher FeO contents are calculated from measured total iron contents, ranging from 0·5–1%. There is evidence* to show, however, that this iron comes mainly from two sources : (i) iron particles in the slag which are not removed in a rough magnetic separation, although they can be almost entirely eliminated by a thorough treatment; (ii) iron present as FeS—the FeS activity in the metal being about 0·03 (relative to pure FeS) for 0·1% of S in carbon-saturated metal.

If slag and metal are as far out of equilibrium with respect to sulphur as all this work indicates, it should be practicable to make a ladle desulphurization of blast-furnace metal with blast-furnace slag in a carbon-lined ladle, with materials which are to hand, and are already hot, and which are less objectionable than soda.

Can Dr. Austin say whether the work of Filer and Darken supports the view that the rate-controlling steps in these slag–metal reactions are the diffusion of reactants and resultants to and from the slag–metal interfaces ?

Dr. **K. J. Irvine** (University of Leeds) : The author shows that with Lake-ore practice the amount of carbon is governed by the requirement of carbon as a reducing agent ; therefore improvements such as ore sizing, elimination of fines, and high-pressure operation will be of more immediate concern than oxygenation of the blast and high blast temperature. (This conclusion is supported in the paper by Mr. Rice.) It is therefore desirable that the maximum amount of information should be obtained about the actual conditions in the reduction zone.

Laboratory experiments give useful information about the structure of the ore, porosity, and rate of reducibility; but the actual reactions occurring inside the furnace, distribution of materials, and the efficiency of gas–solid contact are more difficult to study and it seems that one of the most valuable indications, the composition of the gas leaving the furnace, is largely being ignored.

To determine this a continuous gas analysis from a complete cross-section of the furnace is essential. Joseph† has shown how variations in the top gas composition can give information on the reactions occurring in the furnace. Calculations applied to cover a wide range of variables show that the top gas composition, although relatively insensitive to variations in the amount of carbon burnt at the tuyeres, is very sensitive to those reactions in the furnace, in which carbon is burnt away from the tuyeres, described variously as solution loss and direct reduction, and which have such an effect on the efficient working of the furnace.

Certain of the observations made by Joseph have a direct bearing on some of the points made by Dr. Austin. Figure 3 of the paper by Joseph shows the effect of carbon burnt at the tuyeres and away from the tuyeres, on the CO/CO_2 ratio in the reduction zone. The only definite value known at 850° C., for example, is the equilibrium value of the gases with iron oxide at this temperature. Little is known of the kinetics of the reduction reaction, but, to enable the reduction to proceed at an appreciable rate, a CO/CO_2 value higher than the equilibrium value will be necessary, and a ratio of 3 is assumed. Gas of this composition is produced by burning 1200 lb. of carbon at the tuyeres with a solution loss of 108 lb. ; without any solution loss it would be necessary to burn about 1700 lb. of carbon at the tuyeres. This confirms the point made by Dr. Austin that with Lake-ore practice some direct reduction appears to be desirable.

Two further conclusions can be drawn. Typical Lake-ore practice consumes about 200 lb. of carbon, away from

* T. P. Colclough, International Foundry Congress, 1949: *Metalen*, 1950, Pt. I, pp. 14–30.

† F. D. Richardson and J. H. E. Jeffes, *J. Iron Steel Inst.*, 1949, vol. 163, pp. 397–420

‡ *J. Met.*, 1949, vol. 1, pp. 274–284.

* *J. Met.*, 1949, vol. 1, pp. 274–284.

† T. L. Joseph, *Trans. Amer. Inst. Min. Met. Eng.*, 1951, vol. 189, pp. 37–43 ; *J. Met.*, 1951, Jan.

the tuyeres, whereas it has been shown that 100 lb. provide sufficient reducing power. A reduction of 100 lb. of carbon used in this way would make available about 1,000,000 B.Th.U. to the process. Provided that improvements, such as ore preparation, could be made, which would increase the rate of reduction, and thus reduce solution loss, a significant decrease in coke rate would result. This assumes an arbitrary CO/CO_2 ratio of 3, which was chosen for lack of other information. If the improvements in the rate of reduction enable a closer approach to be made to the equilibrium value, then further decrease in coke rate would be possible.

Gas analyses of the above type have been published by Stapleton,* and experiments have been made elsewhere. Does Dr. Austin think that such measurements yield useful information and can he say whether any work of this nature is being carried out ?

Dr. **S. Klemantaski** (B.I.S.R.A.) : The author's broad survey refers only briefly to carbon deposition, and that mainly from the point of view of its effect on refractories ; yet it seems likely that carbon deposition has an important influence on the blast-furnace process, not only by disrupting the ore and causing swelling of the burden, but also by modifying the balance between indirect and direct reduction.

Our experimental work† on ore reduction, with CO-containing inhibitors of carbon deposition, showed that the rate of low-temperature reduction could be greatly increased by preventing carbon deposition. Although conditions in the blast-furnace are not those of the laboratory, the results suggest that, by hindering ore reduction in the upper part of the furnace, carbon deposition increases the concentration of oxygen in the lower part. Because of the deposited carbon, the carbon concentration is also increased in the lower part of the furnace. The combination of these two factors—increased concentrations of oxygen and of carbon in a suitable temperature zone—must tend to favour direct reduction. I venture to suggest that if the proposal of the Bone-Saunders school that ores should be assessed for their effect on carbon deposition as well as their reducibility, had been followed up, our control and understanding of the blast-furnace process might be better.

As the author mentioned, and as other workers and we ourselves have confirmed, carbon deposition is very sensitive to the presence of traces of impurities in the gas. I should be glad if the author, besides giving his views on the place of carbon deposition in the blast-furnace process, would mention any unpublished work on this aspect of the reaction.

CORRESPONDENCE

Mr. **B. G. Baldwin** (Imperial College of Science and Technology) wrote : Dr. Klemantaski referred in the spoken discussion to the possible importance of the low-temperature deposition of carbon. Experiments that I have recently carried out to compare the reactivities of deposited carbon and cokes towards CO_2 have shown that the amount of deposited carbon consumed in a CO_2/N_2 gas stream at 1000° C., in a given time, was 5–9 times more than that of coke. The presence of this very reactive form of carbon in the lower portion of the furnace and the variation in the amount is certain to have an appreciable effect on the solution losses.

It is essential that the amount of carbon deposited in the blast-furnace be determined before one can achieve a thorough understanding of the process.

Dr. **J. Taylor** (Royal Technical College, Glasgow) wrote : Dr. Austin states that " in many modern blast-furnaces using coke at the rate of 1600–1800 lb./ton, the reduction reactions are operating close to equilibrium and therefore at a high-carbon consumption efficiency." This conclusion is based on the CO/CO_2 equilibrium at 815° C. and the thermal requirements per ton of iron. Although it is impossible to say what is the minimum temperature at which we may expect to approach the CO/CO_2 equilibrium in the blast-furnace, it is surely much lower than 815° C. A CO/CO_2 ratio of 1·4 for the top gas has been reported by Tigerschiold* ; this represents a minimum target at which to aim. Recent data† show that the figure of 13,000,000 B.Th.U./ton for the thermal demands of the furnace to be much too high. The determined value for a 20-ft. basic furnace using mostly hematite ores and a slag weight of about 9 cwt./ton was 9,200,000 B.Th.U./ton. For these conditions the carbon rate, corresponding to a CO/CO_2 ratio of 2·46, was 1430 lb./ton. From this it may be estimated that at a CO/CO_2 ratio of 1·4 the carbon rate should be about 1200 lb./ton and a rate of this order has been recorded by Tigerschiöld. It would be unfortunate if a carbon rate of 1440–1620 lb./ton (equivalent to the coke rate quoted above) were accepted as representing a close approach to theoretical efficiency for this type of practice.

To say that " in most furnaces some significant proportion of the reduction must be carried out directly " is misleading. The more efficient the operation for any given set of conditions and the greater the thermal load, *e.g.*, slag volume, the less is the proportion of direct reduction. But even in the most efficient lean-ore practice, the amount of direct reduction is considerable, and in less efficient rich-ore practice the major proportion of reduction is direct.

AUTHOR'S REPLY

Dr. **Austin** wrote in reply : The temperature of 900° C. has no special significance but was selected as a suitable temperature for illustrating the method by which the data presented in Fig. 2 were derived. My statement that many blast-furnaces may be operating close to equilibrium, referred to the reduction of ferrous oxide by carbon monoxide. Mr. Hacking is correct in saying that the hearth temperature of a ferromanganese furnace need not be greater than that of a furnace producing basic iron. What I intended to state was that the heat required to produce ferromanganese is greater than that required to produce basic iron.

I am unable to provide Dr. Chesters with an adequate explanation of the durability of a carbon lining in the stack ; it may be that the stack gases approach equilibrium with the lining, but I believe that reaction rate may be a more significant factor. The thermal conductivity of carbon refractories is, as Mr. Hacking states, relatively very high, so that the temperature of the inner surface of the lining may be low enough for the reaction to be very slow.

Dr. Irvine asks about the possible usefulness of measurements of top-gas composition. My company believes that data of this kind are significant and measurements are continuing at our plant at South Chicago. The results to date are, however, less informative than had been hoped.

* J. M. Stapleton, *Trans. Amer. Inst. Min. Met. Eng.*, 1943, vol. 154, pp. 62–90 ; *Met. Tech.*, 1943, vol. 10, Tech. Pub. No. 1541, Jan.

† Not yet published.

* M. Tigerschiöld, *Stahl u. Eisen*, 1950, vol. 70, pp. 397–403.

† J. Taylor, R. P. Towndrow, and J. D. Gilchrist, *J. West Scotland Iron Steel Inst.*, 1948/49, vol. 56, pp. 126–144.

The question raised by Dr. Klemantaski as to the influence of inhibitors on carbon deposition is proving to be unexpectedly complex, and investigations have not progressed sufficiently far for me to give any results at present.

Dr. Richardson's question regarding his assumption that at 1480° C. slag and metal were both in equilibrium with carbon, is rather difficult to answer because the slag contains more than one oxide which might react with carbon. Dr. Darken's view is that whereas the metal may approach equilibrium with carbon, it is questionable whether the reactions between carbon and iron oxide or manganese oxide in the slag approach equilibrium in the hearth of a blast-furnace. The work of Darken and Filer does not give any indication of the rate-controlling steps in these slag–metal reactions. Dr. Darken suggests that we must not lose sight of the fact that we are dealing with three phases—slag, metal, and gas—and that the difficulty of nucleating bubbles of carbon monoxide in the liquids collected in the hearth may be a significant factor in determining the rate of hearth reactions.

Discussion on the Paper—

THE PRESENT POSITION OF THE CONVERTER PROCESS : ECONOMIC COMPARISON WITH OTHER STEELMAKING PROCESSES*

By B. Matuschka

Dr. **Matuschka** (United Iron and Steel Works, Linz) briefly presented his paper and added : A correction to some of the figures given at the foot of p. 44 is necessary. The ingot cost per ton should read :

	(*a*) Scrap price £6 13*s.* 0*d.*/ton	
	Pig Iron/Scrap Ratio : 1/1	Pig Iron/Scrap Ratio : 7/3
Open-hearth plant only	£12 10*s.* 0*d.*	£13 10*s.* 0*d.*
Converter using oxygen and stahleisen	...	£13 6*s.* 0*d.*
Converter using induction heating and stahleisen	£12 7*s.* 0*d.*	£12 15*s.* 0*d.*
Basic Bessemer converter (no scrap)	£12 19*s.* 0*d.*	
	(*b*) Scrap price £3 6*s.* 0*d.*/ton	
	Pig Iron/Scrap Ratio : 1/1	Pig Iron/Scrap Ratio : 7/3
Open-hearth plant only	£10 16*s.* 0*d.*	£12 7*s.* 0*d.*
Converter using oxygen and stahleisen	...	£12 6*s.* 0*d.*
Converter using induction heating and stahleisen	£10 13*s.* 0*d.*	£11 15*s.* 0*d.*
Basic Bessemer converter (no scrap)	£12 19*s.* 0*d.*	

Mr. D. F. Campbell (Electric Furnace Co., Ltd.) : Dr. Matuschka's paper comes at a time when the wider use of the basic Bessemer process, with modern refinements, may be applicable to the conditions arising from the shortage of scrap and of iron ores. The economics of steelmaking are made difficult by the anomaly of the price of scrap, which is now the equivalent of 230*s.*/ton in Pittsburgh and only 80*s.* in this country, and by the low selling price often fixed for basic slag.

On the Continent, serious difficulty has occurred with the basic Bessemer process in the last few years owing to the introduction of strip mills for the production of high-quality sheet for deep pressing. Satisfactory strip cannot be rolled from the old-quality basic Bessemer steel, and the author's suggestions for improving its quality are of immediate interest. The main problem is to avoid the introduction of nitrogen.

The relative advantages of blowing with oxygen, oxygen and steam, and oxygen and CO_2, and of the Perrin process, and the advantages, if any, of combining a converter with an induction furnace over duplex working, for the finishing and alloying of special steels, should be the subject of fruitful and interesting discussion.

Dr. Ing. **R. Durrer** (Louis de Roll Iron Works, Ltd., Switzerland). Successful tests have been carried out using oxygen for the oxidation of pig iron in a 2½-ton converter in Switzerland, with both acid and basic lining. The difficulties experienced in Austria with large 15-ton converters using high-phosphorus pig iron have been overcome in the small converter. Mr. Suess will say something about the work on the 15-ton converter.

If the concentration of oxygen used is sufficiently high, the nitrogen content of the finished steel can be even lower than that of open-hearth steel and, by this elimination of nitrogen, so much heat is saved that more than half the weight of pig iron blown into steel may be melted in the form of scrap. With modifications in the blast-furnace process more ores should be suitable for smelting and no difficulty should arise with high-silicon ores. Even more heat should be saved, with a still greater quantity of recoverable scrap.

In Switzerland, electric steel furnaces are used partly as converters : this has previously been done with scrap but not generally with pig iron. The consumption of electric energy has been reduced to about two-thirds of that required for ordinary working, and the operating time has been considerably shortened.

Dr. Tech. **T. E. Suess** (Vereinigte Osterreichische Eisen- und Stahlwerke A.G., Linz and Donau, Austria) : Austrian metallurgists have recently concluded tests on the production of high-purity steel from 0·13% phosphorus–manganese pig iron. Austria has deposits of ore but has insufficient quantities of coal for economic working of the open-hearth process. After several large-scale investigations on blowing iron in the basic

* *J. Iron Steel Inst.*, 1951, vol. 168, May, pp. 40–45.

Table A

ANALYSIS OF OXYGEN-BLOWN STEEL

No.	Description and Use	C, %	Si, %	Mn, %	P, %	S, %	Al, %	N_2, %
1	Special steel for cold-working, deep-drawing, and galvanizing	0·020	...	0·17	0·010	0·011	...	0·005
2	Low-carbon rimming steel for cold-working, and deep-drawing	0·10	...	0·39	0·019	0·018	...	0·005
3	Low-carbon killed steel for cold-working, and deep-drawing	0·07	0·07	0·44	0·019	0·010	0·013	0·005
4	Medium-carbon rimming steel, structural steel, shipbuilding steel BSS 15	0·18	...	0·55	0·027	0·021	...	0·006
5	Medium-carbon killed steel, shipbuilding steel, boiler plate	0·19	0·17	0·64	0·036	0·013	0·057	0·006
6	Aluminium-bearing special steel for high-stressed welded constructions resistant to cleavage	0·20	0·47	1·49	0·034	0·017	0·029	0·007
7	Structural steel for ships (high-tensile)	0·29	0·42	0·72	0·035	0·015	...	0·004
8	Medium-carbon forging steel, tensile strength 36 tons/sq. in.	0·35	0·22	0·55	0·039	0·023	...	0·007
9	Medium-carbon forging steel, tensile strength 43 tons/sq. in.	0·43	0·21	0·80	0·050	0·025	...	0·005
10	Steel for rails and tools	0·55	0·21	1·00	0·031	0·010	0·035	0·006

Table B

MECHANICAL PROPERTIES OF OXYGEN-BLOWN STEEL

Steel No.	Yield Point,* tons/sq. in.	Tensile Strength,* tons/sq. in.	Yield Point / UTS, %	Elongation, %	Reduction in Area, %	Impact† Value, mkg./sq. cm.	Deep-Drawing Test‡ (Erichsen), mm.
1	13·3 (20·7)	20·4 (32·2)	64	33·8	76	18·7	11·7
2	15·0 (23·7)	22·4 (35·4)	67	39·7	67	20·5	11·0
3	12·8 (20·2)	23·6 (37·4)	57	32·6	69	20·1	10·6
4	18·4 (29·0)	27·6 (43·7)	66	27·5	60	16·2	10·3
5	21·0 (33·1)	30·5 (48·3)	69	27·0	63	15·8	...
6	26·4 (41·6)	36·8 (58·2)	72	25·0	63	16·5	...
7	23·3§ (36·7)	36·8 (58·2)	63	29·0 23·2¶	56	14·8	...
8	19·4 (30·6)	22·4 (35·4)	55	30·0	52	7·0	...
9	24·2 (38·2)	43·1 (68·2)	56	23·0	47	4·1	...
10	29·0 (45·8)	54·0 (85·4)	54	16·2	33	...	...

* Figures in brackets are in kg./sq.mm.
† DVMr specimen
‡ 1 mm. gauge thickness
§ Limit of proportionality 17·0 tons/sq. in (26·5 kg./mm.)
¶ 200-mm. gauge length

converter and, following a suggestion made by Professor Durrer, in May, 1949, investigations were started at Linz and Donawitz, on blowing pure oxygen on to the surface of the molten iron in a vessel similar to a Bessemer converter. Several thousand tons of steel of different qualities have now been produced by this process. The oxygen consumption is approx. 2120 cu. ft. (60 cu. m.) per ton of pig iron and the scrap addition varies between 12 and 30%. The nozzle has a very satisfactory life, and the wear of the refractory is similar to that of an ordinary Bessemer converter. The chemical compositions, mechanical properties, and uses of some of these steels are given in Tables A and B.

Table C—COMPARATIVE PRODUCTION COSTS

	Annual Production, tons		
	150,000	300,000	600,000
Open-hearth steel, %	100	100	100
Oxygen-blown steel, %	91	90	90
Converter process with stahleisen, %	95	94	94

Comparative costs per ton of steel at an annual production of 150,000, 300,000, and 600,000 tons made in the open-hearth furnace by the oxygen-blowing method, and by the Bessemer converter process with stahleisen, are given in Table C. Assuming that the open-hearth furnaces and converters worked with 70% of pig iron and 30% of scrap, oxygen-blown steel had the lowest production cost : under Austrian conditions this is true even with 50% of pig iron and 50% of scrap in the charge.

The figures given in Table D show that investment costs for the oxygen process, including the oxygen plant, are considerably lower than those for an open-hearth or converter plant of equal capacity ; its smaller size is also a consideration. No open-hearth furnaces are therefore being built at Linz or at Donawitz. However, where adequate scrap is available at a favourable price, the open-hearth process is cheaper than the oxygen blowing process but, because of the present world shortage of scrap, many works are operating the pig-and-ore process with more than 50% of pig, and in this case oxygen-blown steel is cheaper than the open-hearth product.

Mr. **W. L. Kerlie** (Stewarts and Lloyds, Ltd., Corby) : I agree with the author's conclusion given on p. 43, but a few points require some clarification.

In Table 1*b* the lime consumption is given as 50 kg./ton, although the normal basic Bessemer practice entails a lime consumption of approx. 150 kg./ton. Refractories consumption in basic Bessemer practice is generally only a half to one third of that in open-hearth practice. I should also like further information on the type of iron, at £10/ton, that is suitable for both open-hearth and basic Bessemer sections. Was a relatively low-phosphorus iron used ? In the basic Bessemer section, a scrap credit of only 1*s.* 8*d.* seems rather low when the yield is 87%, and the total uprising scrap might be about 55 kg./ton. Should this credit also be based on the scrap prices used, *i.e.*, £6 13*s.* 0*d.* and £3 6*s.* 0*d.*, respectively, giving, say 4*s.* and 2*s.* respectively, or was the scrap credited at a specially low price ?

Can the author indicate the capacity of the open-hearth and basic Bessemer units used in assessing the cost given in Table 1*b*, and say whether any allowance has been made for capital charges ? As the author's data show, the important items affecting the ingot cost, are (i) proportion of pig iron to scrap, (ii) prices of pig iron and scrap, and (iii) operating costs.

The author mentions on p. 43 that, if the price of scrap is about two-thirds that of pig iron, the ingot cost for a basic Bessemer works is about equal to that for a modern open-hearth plant working with 50% of pig iron. For ironmaking, if the scrap price falls below two-thirds of the normal iron cost, using ore, it becomes economically advantageous to use a large amount of scrap in the blast-furnace. One would expect, therefore, that the natural value of scrap in any given locality would be two-thirds of the iron cost, using an essentially ore burden ; in a locality where ore is easily won and freightage costs for scrap are high it will be economically sound to concentrate on smelting as far as possible with ore, operating mainly on the basic Bessemer process for steelmaking and using the open-hearth process for the uprising scrap balance.

Bading,* using 2% phosphorus iron at almost £10/ton, gives the ingot cost for a 30-ton converter as £12 6*s.* 0*d.* and for a 250-ton furnace, using a high proportion of iron, as £12 16*s.* 0*d.* These comparative figures are in agreement with those given by the author.

In Table II the author indicates, by comparison with Table 1*b*, that the operating cost using oxygen increases by about £1/ton : this appears to be excessive. For example, the oxygen required to convert Thomas iron is about 2000 cu. ft./ton. The price of tonnage oxygen will decrease with increasing size of oxygen plant, and for an oxygen consumption of 100 tons/day the price of oxygen will be about 2*s.* 6*d.*/1000 cu. ft., and the increase in ingot cost will be about 5*s.* Lower cost figures than these may be possible by using oxygen for 50% of the conversion only, or, alternatively, by using oxygen with steam.

The idea of induction heating in the converter is intriguing, particularly for the production of alloy steels from suitable iron, but there would appear to be structural difficulties in the design of such equipment, and the maintenance and repair costs might be very heavy ; more information would be welcome. The refining cost of 11*s.* 8*d.*/ton given in Table III for induction heating in a basic converter appears to be very low.

Mr. **H. Parnham** (General Refractories, Ltd.) : Would the author give the relative cost of the refractories used in the basic Bessemer converter and in the open-hearth furnace, bearing in mind that dolomite, used in lining basic converters, is a cheap raw material, whereas large quantities of chrome ores and magnesite, both of which are expensive, are used in the latter process ?

Have there been any developments on the Continent for improving both the life of the side wall and of the tuyere section of basic Bessemer converters ? What is the minimum lining thickness envisaged for converters with induction heating ? The fact that oxygen blowing is applied to the surface of the bath may reduce some of the tuyere problems, but will any damage to the lining result ? Can repairs be carried out quickly and effectively to keep the refractories costs down ?

Dr. Tech. **Suess** : The converters are stamped with tar dolomite, and the consumption of dolomite is about 34 lb./ton of steel. The life of the lining of the converter is influenced by the operating practice, but is between 150 and 250 heats. Small repairs may have to be done during the weekends.

* W. Bading, *Stahl u. Eisen*, 1951, vol. 71, pp. 373–388.

Table D
COMPARATIVE INVESTMENT COSTS

		Annual Production, tons		
		150,000	300,000	600,000
Open-hearth steel	**No. of O-H furnaces (200 tons each)**	2	4	8
	Investment costs, %	100	100	100
Oxygen-blown steel	**No. of converters (30 tons each)**	2	3	5
	Investment costs, %	56	38	39
Converter-process steel with stahleisen	**No. of converters (30 tons each)**	2	3	5
	Investment costs, %	75	60	53

Dr. **T. P. Colclough** (British Iron and Steel Federation) : There are a few points in the paper which I think require a little revision. For example, on p. 41, in the statistics given for the production of steel in Europe, there is no mention of Germany, but I believe that Germany does produce some steel and is likely to continue to do so. The author states that Germany makes basic Bessemer steel from the Minette ores of Lorraine, but this is only true if the author is including the Saar in Germany. I think that two figures have been transposed in the penultimate paragraph on p. 41, where it is said that the 36% of basic Bessemer steel produced allows the percentage of scrap used in open-hearth furnaces to be as high as 57%. I think that this should be 75%. If the average for the whole industry is 52% of scrap, and 36% of steel is produced by the Bessemer process, where no scrap is used, there must be considerably more used in the open-hearth process.

The serious shortage of scrap, envisaged by the author (p. 41) as a result of an increase in steel production from 50 to 60 million tons, should not persist for more than a few months, since increased production will be accompanied by a corresponding increase in circulating scrap.

The author says " The essential condition for using the open-hearth process is that the price of scrap should be lower than that of pig iron," but in some works in this country 70–80% of pig iron is always used in the open-hearth charge, irrespective of the scrap price. The large tilting furnace might usefully be compared with the ordinary cold-metal melting open-hearth furnace.

No one process of steelmaking can be made universal, and the choice of process must depend on the economics of a particular locality and not of a wide area. The effect of the price of oxygen on the economics of the process determines how far the author's recommendations for the increased use of oxygen in steelmaking can be applied. The capital expenditure involved in the installation of open-hearth furnaces, compared with other types of steelmaking plant, and of the oxygen plant, and the power-generating equipment, must be considered.

The technique and possibilities of the use of oxygen in the steelmaking processes, whether Bessemer, open-hearth, or electric, are fairly well known, and experience has been gained in the U.K. of its application to all three processes. Experiments and practice in this country have established that the steel made in converters blown with oxygen carries a nitrogen content similar to that of good open-hearth steel and does not suffer the disadvantages of ordinary Bessemer steel, which arise from the high nitrogen content. All the practical difficulties, however, have not yet been overcome—the tuyeres and the refractories give trouble and the large volume of the red fumes produced is a public nuisance, particularly where the steelworks are near a town.

Mr. **C. Danielsson** (Domnarfvet Iron and Steel Works, Sweden) : Referring to the remarks made by Dr. Durrer, a simple process, devised at Domnarfvet, is now in commercial use at one of our Swedish plants for obtaining a low-sulphur pig iron from a blast-furnace operating with a very acid slag. Finely ground lime, thoroughly mixed with molten pig iron, will lower considerably the sulphur content of the iron. By this treatment, 0·1% of sulphur was reduced, in 800 casts, to an average of 0·01%. The treatment is carried out in a special rotary furnace.

The **President** (Mr. Richard Mather) : The paper marks a further stage in the increasing tendency, which began in this country about 20 years ago, for a re-examination of the possibilities of the Bessemer process. Whether we shall find economic possibilities in its still further development depends, among other factors, on the qualities of the steel which can be made, and this paper gives some pointers towards further improvement.

CORRESPONDENCE

Dr. **Colclough** wrote : I believe the first experiments in partial blowing of pig iron with air or oxygen-enriched blast were carried out by Dr. Röchling at Volklingen about 1937. Röchling found that, because of its preferential rate of oxidation, the small amounts of vanadium from the lean ores of Lorraine could be eliminated by blowing, before any substantial oxidation of carbon, manganese, or phosphorus had occurred. He placed a cylindrical kiln round the runner from the blast-furnace and blew jets of air over the surface of the liquid pig iron as it was tapped from the blast-furnace. These air jets oxidized the silicon and vanadium but left the other elements almost unchanged. The slag thus formed was charged into a small blast-furnace and re-smelted, yielding a pig iron containing appreciable percentages of vanadium and phosphorus. This enriched iron, if blown for a few minutes, yielded a slag comparatively rich in vanadium oxide from which metallic vanadium could be extracted. A modification of this process* was in general use in Western Europe during the war and was Germany's main source of supply of vanadium. We applied this principle of preferential oxidation to the study of the Austrian ores during 1938 and 1939, when plans were being prepared for the erection of the steelworks at Donawitz and Linz. The ankarit ore of the Erzberg, which is the main source of iron ore in Austria, carrries a relatively high proportion of manganese and, with a suitable burden in the blast-furnace, can be made to yield a pig iron with 3% of manganese and a low phosphorus content. We came to the conclusion that with a blowing time of 4–5 min., it would be possible to remove all the silicon and leave a liquid metal of about 1% of carbon and 1% or a little less, of manganese, giving a slag with 30–35% of manganese, which could be smelted in a small blast-furnace to yield ferro-manganese or spiegeleisen. Experimental blows indicated that the principles were sound and that the operation was practicable. A repetition of the tests has confirmed these results.

There is no doubt that this partial blowing can be carried out with oxygen as well as with air, but it is difficult to see the advantages of oxygen blast because the heat generated by the ordinary air blast by the oxidation of silicon and manganese is greater than that necessary for the thermal requirements of the process. I suggest that the heat tables on p. 45 require some slight amendment, since no heat is attributed to the oxidation of silicon. The figures for manganese should be 2·5–0·5% instead of 1–0·5, and I am not aware that it is possible to remove phosphorus in an acid-lined converter.

AUTHOR'S REPLY

Dr. **B. Matuschka** said in reply : It is difficult in an economic investigation to deal with all the situations which arise in the world, and therefore I have based my paper on the present conditions in the open-hearth process and in the Bessemer process. The figures may have to be corrected for special conditions which may be found in this and other countries. The basis of my calculations is the price of pig iron, which is always a very important factor. Taking the price of pig iron as 100, the calculations are based on two scrap prices, one

* T. P. Colclough, *Combined Intelligence Objectives Sub-Committee*, File No. XX-6. H.M. Stationery Office.

of 66 and the other of 33. The conversion costs of the open-hearth process are about 33% of the pig-iron price. The conversion costs of the converter with slag recovery are about 8%, and without slag recovery about 14%. The conversion cost of the oxygen converter is 24%, and of the induction converter 20%. These are fundamental figures and can be used in making the calculations for special conditions. The different processes will give different results under different specific conditions, which I have not discussed. I have not even discussed Austrian conditions, because these are special conditions and cannot be generalized.

Incidentally, the first item in the table in paragraph 6, p. 44, should be £1 8*s.* 6*d.* instead of 11*s.* 8*d.*) making totals of £2 0*s.* 6*d.* and £2 5*s.* 2*d.*

The discussion has shown that there is a general interest in this problem. The technical aspect of the converter process is important as well as the economic aspect, and further development of the conditions existing in the various processes, will influence the economic aspect as well as the technical one. I shall be pleased to give my opinion on special conditions if I am given the particulars.

A further written reply to the discussion has been received, too late for publication here. It will be printed in the March issue of the Journal.

Joint Discussion on the Papers—

SOME ASPECTS OF THE BLAST-FURNACE SITUATION IN THE UNITED STATES*

By Owen R. Rice

EVOLUTION OF THE ALL-CARBON BLAST-FURNACE†

By J. H. Chesters, G. D. Elliot, and J. Mackenzie

and—

RADIO-ACTIVE INDICATORS FOR BLAST-FURNACE REFRACTORY WEAR‡

By E. W. Voice

Mr. Rice (Freyn Engineering Department, Koppers Co., Inc., Chicago), whose paper had not been available in print before the meeting, presented it in full (*see* this issue p. 89).

Mr. J. Mackenzie, after introducing the second paper on the evolution of the all-carbon blast-furnace added : Examination of blown-out bottoms at Appleby-Frodingham, of inverted arch and corrugated design, and evidence from other furnaces and from other countries, show that in all cases the centre of the carbon bottom had disappeared. Carbon had thus been removed by some mechanism. Our recent work on the relationship of carbon to iron shows that this cannot be attributed entirely to mechanical failure. I would like to add the name of Mr. J. R. Lakin to those of the authors in being closely concerned with this work.

A coke-type carbon brick of British manufacture, an American carbon brick, which has a coarse-grained texture and is a mixture of anthracite, amorphous and graphitic carbon, and a graphite bar cut from an electrode were cut into bars, 9 in. long with a 1-in. square section. The bars were placed in a holder and immersed in a pot of Appleby iron§ held in an induction furnace at 1500° C. for 5 hr. with a covering of coke breeze to prevent oxidation. After test the metal separated cleanly from all the bars.

The amorphous carbon bars were unaffected by the treatment, apart from the occurrence of small thermal shock cracks. The American carbon brick, however, had lost a few of its characteristic large grains, apparently by preferential attack on the matrix ; the surface appeared etched. The graphite bar was reduced to about half its thickness where it had been in contact with the metal ; at the metal line, around the bar, loose graphite crystals which had floated to the surface of the metal were deposited. This behaviour may explain the appearance of the American carbon brick, which has a graphite matrix. The evidence that graphitic carbon can be dissolved or washed from a bar in contact with molten pig iron only affects those bricks, such as the American carbon ones, which contain a proportion of graphite. Since laboratory work and observations on blown-out hearths have shown that amorphous carbon tends to graphitize in service in a bottom, it would be expected that the carbon refractory would gradually disappear. Graphitization and loss of carbon are effectively prevented in the hearth walls and breakouts are avoided, apparently because the efficient cooling of the hearth jacket by sprays or staves maintains a steep temperature gradient through the carbon wall, and, therefore, prevents penetration of iron, and maintains the greater part of the wall at a temperature too low for graphitization or removal to take place. A similar system has been suggested¶ for cooling under the carbon of the bottom, but has not been considered practical by blast-furnace operators. An arrangement for the cooling of a carbon bottom by means of air pipes has been designed at Appleby-Frodingham, and it is hoped that this will preserve the carbon refractory and eliminate salamanders.

Experience at Appleby-Frodingham suggests that it may be desirable to build the bottom of the stack in carbon, to prevent scaffolding, and the top third in dense, well-burned fireclay bricks, specially designed to resist abrasion and carbon deposition.

The building of the all-carbon furnace has been justified by the experience gained, by freedom from breakouts and scaffolds, and, of immediate importance, by the extra iron made. This is illustrated by

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* Copies of this paper were available at the meeting.
† *J. Iron Steel Inst.*, 1951, vol. 167, Mar., pp. 273–282.
‡ *Ibid.*, 1951, vol. 167, Feb., pp. 157–161.
§ Carbon 3·5%, silicon 1·0%, sulphur 0·075%, phosphorus 1·5%, and manganese 1·0%.
¶ *Iron Steel Inst., Spec. Rep.* No. 30, 1944.

the following figures for all-carbon furnaces, obtained with a burden in which the iron content had decreased and the sulphur content had increased when compared with earlier campaigns.

No. 6 *Furnace*—worked 111 weeks and made 11·43% more iron than in the previous campaign

No. 1 *Furnace*—worked 82 weeks and made 8·27% more iron than in the previous campaign

No. 5 *Furnace*—worked 48 weeks up to the time of blowing-out (because of foundation trouble) and made 3·33% more iron.

Mr. **E. W. Voice** (B.I.S.R.A.) presented the third paper on radio-active indicators for blast-furnace refractory wear.

Mr. **R. P. Towndrow** (Colvilles, Ltd.): Mr. Rice has indicated a number of marked differences between British and American practice. Most of us have tried to fit British data with the Freyn (or Rice) rating for the coke-burning capacity of a blast-furnace. Not only does the average coke-burning rate of the British furnace fall far below that of its American counterpart but this rate varies considerably from district to district. Of six large modern furnaces investigated by the Blast-Furnace Committee, there was at least a 15% difference between the fastest and the slowest coke-burning furnace. Mr. Rice draws a clear-cut distinction between southern and northern operation in America; similar equally marked differences occur in Britain between those furnaces using entirely rich imported ores and those using nothing but the lean home ores. In the latter group, one limitation to the rate of blowing may be in the high volumetric ratio of ore to coke. This, together with the difficulty of completely screening the fines, imposes an early limit on the rate at which a furnace can be blown without causing irregular stock movement and high flue-dust loss. Most operators believe that an undue sacrifice of smooth furnace operation does not pay dividends in terms of coke rate, lining life, and ultimate production.

The reasons for the lower operating rates of furnaces at the other end of the scale are, I believe, entirely different. Here, particularly if the ore is adequately screened, there appear to be few physical reasons why higher blowing rates should not be used. Furnaces working on rich ores usually drive smoothly under most conditions with a reasonably low flue-dust production. The difficulty of reducing burdens consisting mainly of dense Swedish ores in the furnace stack, however, rapidly leads to unduly high coke rates if the speed of operation is increased too far. Prolonged operation at about 76% of the Freyn rating has given coke rates of 1660 lb./net ton with a slag volume of 1078 lb./net ton; these rates compare favourably with the United States figures quoted in Table VI. Some furnaces in Britain are, in fact, operating at substantially lower coke rates. That the coke rate does not increase with the rate of blowing until 100% rating is achieved may be true for United States practice at a rating of 85% or more, but it does not apply to British practice where poorly reducible ores form a large part of the burden.

For example, when the Clyde furnaces are provided with materials producing a slag volume similar to that quoted for United States practice, *i.e.*, approx. 1060 lb./net ton, then they can make approx. 700,000 net tons of pig iron per year at a coke consumption of approx. 1640 lb./net ton. This represents 76% of the Freyn rating. If the rating is increased to 100% and the coke consumption increases to 1790 lb. (the figure quoted for United States practice), then, although production will increase to 845,000 net tons of pig, the anticipated profit would be reduced by approx. £120,000. To prevent a loss, the coke consumption at the 100% rating must not rise above 1700 lb./net ton. It is doubtful whether this is possible with the materials at present at our disposal. The advantages accruing to the rest of the steelmaking organization must be added to the credit side.

In the author's comparison of furnace performance of coke from washed and unwashed coals, is the marked reduction in variation achieved, perhaps more important than the reduction in the absolute values of the variables considered? I agree with the author's insistence on the furnacemen's privileges in regard to the final screening of coke.

Much attention has been given to the reasons why furnaces break out, but less attention has been given to furnaces that have not broken out. Fireclay refractories can be very successful in the hearth of a blast-furnace, because of the extremely rigid construction used in hearths that have given trouble-free lives of more than 1½ million gross tons. In these hearths the vertical wastage terminated at a semi-fused monolith at a relatively small depth below the tap-hole, although lateral erosion of the brickwork, in some cases, occurred to within a few inches of the stave coolers. Until a method of securely bonding carbon brick is devised this form of construction will not be wholly satisfactory. However, if proper attention is given to the methods of building a firebrick hearth satisfactory service can be obtained. I consider that the use of carbon in the side walls and well-constructed ceramic for the hearth pad give the best combination of the advantages of both materials.

As the operator of the only example of high-top-pressure practice outside the United States, I can confirm that a great many of the engineering innovations necessary to the successful operation of a furnace on high top-pressure could be applied with very considerable advantage to those working on normal pressure.

With the increasing use of technicians in the day-to-day operation of modern blast-furnace plant and equipment, the disasters that occurred in the past are very rare. Only the technically trained operator can take full advantage of advances in technology.

The paper by Mr. Voice shows the ingenuity now being displayed in developing techniques for exploring the blast-furnace without interrupting its normal functions, and thus avoiding loss of production. The results are also more representative of the working conditions in the furnace.

Mr. **G. D. Elliot** (Appleby-Frodingham Steel Co.): Although I am in agreement with much that Mr. Rice has said, I disagree with what he says about mechanical bin gates. In our desire for labour saving and mechanization we sometimes forget the need for simplification. I am associated with a plant built in 1939 which has 56 ore bins and 560 gates, hand operated. It has always been a one-man stock-house; we have not changed a gate, and we have spent less than £100 on maintenance. You will not get many fitters to maintain mechanical gates for £100.

The Rice rating is a handy yardstick of day-to-day operation, but coke consumption and slag volume, per ton of pig, affect the rating. In Fig. 2 the three Dutch furnaces are in excess of the rating, and all the British furnaces are below the rating. In Table VI the Dutch furnaces have the highest coke rate; the average British furnace has the same coke rate as the

average United States furnace, but the slag volume in Britain is higher than in the U.S.A., indicating that coke consumption and slag volume per ton of pig have an effect on rating. We can burn coke only at the speed at which we can push air through the bed of coke, and high slag volume must affect this speed. Similarly, the low bulk density of British native ores affects the ease with which the Rice rating is achieved.

In regard to Mr. Rice's remarks about blast pressure, we are operating two 22-ft. furnaces at 20–22-lb. pressure, but we are unable to achieve 100% Rice rating, although this rating has been achieved over selected periods. We must aim to get our furnaces to this rating at all times.

Some of our blowing equipment is not powerful enough for such a rating. I believe that a 20% increase in rating would be obtained immediately by proper burden preparation, which would permit hand-blowing. The author's figures show, however, that the addition of top-pressure lifted the Rice rating by only about 2%, and it was still lower than that of American furnaces not so equipped. Although we may not blow sufficiently hard, 100% Rice rating is possible on any size of furnace, provided that the coke, the practice, and the raw materials, are suitable for the particular furnace.

Mr. Rice suggests that increased sinter permits the carrying of higher blast temperatures ; I will go further and say that increased sinter demands higher blast temperatures.

It can be very dangerous to compare cost and practice figures, of one country, or company, with those of another. A campaign output of 1,000,000 tons of iron on a blast-furnace using Lake ores is not the same as an output of 1,000,000 tons of iron from a furnace using home ores. Perhaps the fundamental consideration in drawing any comparisons must be the realization of the raw materials involved.

Mr. **A. T. Ledgard** (Dorman Long and Co., Ltd.) : American blast-furnace practice aims at a high iron output, whilst we, in Britain, are more concerned with coke consumption. I think that the Americans can achieve 100% efficiency with their blowing rates, by working comparable ores at a lower blast temperature than we do. A hanging furnace is returned to normal by either lowering the blast temperature or reducing the wind blown. If we reduce the blast temperature from 1250° F. to the American standard of 1000° F., I think we could safely blow between 3000 and 5000 cu. ft. more blast per minute than the normal blow of 33,000–35,000 cu. ft./min. on an 18-ft. furnace. This would increase the rating from approx. 75% to 90%, but it would be at the expense of coke consumption.

Austin* has stated that oxygen present as water vapour is harmful to the carbonaceous bond of blast-furnace carbon refractories. Although carbon bricks are often bonded with a carbon paste, I do not think that this material will last long in contact with gases or iron. Some workers dislike a ceramic bond because it requires water for mixing ; they contend that water should not be used with carbon, yet they will blow a furnace out and quench it with water, although they wish to use the carbon hearth again for a further campaign.

I think we should limit ourselves to carbon side walls, with the highest grade of firebrick for the centre core. It is now generally accepted that with the full carbon hearth it is essential to have some type of cooling below the pad of carbon. Air cooling using 3-in., 4-in., or even 6-in. pipes has been suggested. Cooling by circulating water through pipes is considered dangerous in an enclosed region adjacent to the molten bath.

Clements† describes the Resita furnace in Rumania, in which the brickwork below the bath is 6 ft. thick ; the whole of the base of the hearth is supported on mild-steel stools and there is a complete air space under the furnace hearth.

Cobalt pellets and radio-active tracers are now essential in blast-furnace research ; with normal blast-furnace tests cobalt tracers should be used on a full-scale trial to give transit times, together with stock-line contouring.

Mr. **J. M. Ridgion** (B.I.S.R.A.) : I have used the Rice index for plotting a considerable amount of British blast-furnace data, obtained over a number of years. The plot for the four-week period in which the various furnaces had burnt more coke than in any other comparable period was very similar to that given for American furnaces (*see* Fig. 2), except, of course, that they did not extend to such large hearth diameters. I have plotted data from about 20 furnaces, obtained during 1950, on Fig. 2 ; they agree closely with the figures given by Mr. Rice for British practice. Bond and Sanderson‡ describe a test on the No. 10 furnace at Appleby-Frodingham in which a 92% rating was reached.

It is helpful to consider the various types of inter-relationships of blast-furnace variables. In statistical analysis it is sometimes difficult to decide which variables are dependent and which independent. For example, the coke rate per ton of pig is considered to be a variable, depending on the iron content of the burden, the slag volume, the blast temperature, the coke quality, and so on. But the coke rate is an independent variable, influencing other factors, because its value is determined by the furnace manager. The major dependent variable appears to be whether the furnace will work ; for southern practice in the U.S.A. it is a question of how will the furnace work under the conditions imposed—a very different thing.

Figure A shows some of the linkages between variables.

Since the iron output is the ratio of the coke burnt to the coke rate, an investigation of the effect of variables on the coke rate and on the coke burnt will give their effect on the output of iron. The slag volume influences the coke rate ; the state of preparation of the burden influences the coke rate and the Rice rating, and to some extent it will influence the flue dust. The amount of flue dust will depend on the wind blown, but the amount of wind ordered by the blast-furnace manager will depend on the flue dust made.

In Table V, Mr. Rice has grouped furnaces of different ratings to show the flue-dust production, coke rate, and so on. He states that as the rating increased the dust production did not increase significantly, and there was little change in the coke rate. I think that he has put it the wrong way round : the various ratings have arisen because the furnace manager has limited flue-dust production, or has kept his coke rate within certain limits. Another

* J. B. Austin, *J. Iron Steel Inst.*, 1951, vol. 167, pp. 358–362.

† F. Clements, "Blast-Furnace Practice," vol. 2, p. 104, London, 1929 : Ernest Benn, Ltd.

‡ J. A. Bond and T. Sanderson, *J. Iron Steel Inst.*, 1951, vol. 168, pp. 24–39.

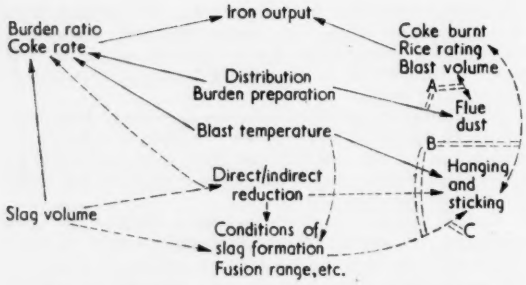

Fig. A—Some of the linkages between variables

explanation is needed to account for the different ratings attained by these furnaces.

Figure A shows that the blast temperature will influence the coke rate directly and will affect the rating, because of hanging. This is a reciprocal relationship because the rating is adjusted to get the hanging conditions which can be tolerated. The southern furnaces in the U.S.A. will stand a worse condition of hanging than the northern.

The relationships between slag volume and blast temperature on the one hand and the proportion of direct to indirect reduction and the mysteries of the slag fusion zone on the other have been discussed by Taylor.* In a system of this kind, which can be complicated by taking into account the iron quality and the iron content of the raw materials, for given raw materials, a given furnace improvement can be brought about by special burden preparation. Certain other factors, however, can interfere with the linkages between variables.

The introduction of high top-pressure at *A* interferes with certain linkages and establishes a new type of relationship between the distribution of gas in the furnace, the preparation of the burden and the rating that the furnace will take ; it may enable the rating to be freed from the limiting influence of flue-dust production. At *B*, following Mr. Rice's advice about southern U.S. practice, it may be possible to overcome the previous limitations of blast temperature. At *C*, by the injection of slag constituents in the lower portion of the furnace, it may be possible to influence slag fusion conditions and improve the ease of driving.

One of the difficulties, however—and I should very much appreciate enlightenment on this—is the factor which I call hanging. There is a very wide variation in the type of irregularity which furnaces experience, and in the methods of overcoming these. Some indication of the obscurities of the question was given in a paper at the Blast-Furnace and Raw Materials Conference† in 1950.

Dr. **J. H. Chesters** (United Steel Companies, Ltd.) : The valuable new American alumino-silicate refractories have extremely low porosity, are very hard burnt, and are volume stable, but I question Mr. Rice's statement that because a brick shows a positive expansion in an A.S.T.M. reheat test it is necessarily permanently free from shrinkage in a furnace hearth. We have yet to find alumino-silicate bricks which, given time, will not shrink. I also question his statement that if the iron in a firebrick for use in the stack can be converted to ferrous silicate it will show permanent resistance to CO distintegration. It is known that a brick, which is stable in the ordinary CO test because the iron is there as silicate, can be made active to carbon deposition by heat-treatment at about 1000° C.

During my recent visit to the United States I was very impressed by research on concentration and agglomeration of iron ores by pelletizing. To separate the magnetite and silica in a hard ore, such as taconite, by grinding to 300 mesh, and then to agglomerate the magnetite by pelletizing, all at a price that may prove competitive with foreign ores, would be an achievement.

Mr. **E. W. Voice** (B.I.S.R.A.) : Dr. Chesters and his co-authors emphasize the importance of carbon having a high thermal conductivity and realize that molten metal would be expected to penetrate lower down a carbon hearth than down a firebrick hearth. Calculation of the temperature distribution under a blast-furnace hearth indicates that there is little temperature drop through the carbon, and molten metal may easily get below it. On one large furnace a thermocouple, installed in the firebrick 8 ft. below the base of 4½-ft. carbon hearth, recorded an actual temperature of 520° C. after six months ; the calculated temperature was 550° C. If the calculated temperature at the base of the carbon (1300° C.) is the true temperature then there would be considerable mechanical upthrust because many blocks would be surrounded by molten metal. In some designs, damage may occur because the concrete foundations reach a high temperature.

It has already been suggested that the carbon hearth should be cooled from below by air cooling ; calculation of the air flow required suggests that the fan power is very small. If the temperature below the hearth is controlled and the iron does not attack the carbon, the hearth should have a long life. The authors' illustrations suggest that some carbon should be suitable for resisting iron attack.

In normal practice carbon side walls are thought to prevent hearth breakouts, but it is not necessarily a suitable material for the hearth floor ; the wall is probably washed and rewashed by slag, whereas the centre carbon pad may not be.

If the hearth is cooled and the bottom of the carbon can be kept below the temperature of freezing metal, the use of tall vertical carbon blocks would have a considerable advantage ; there would then be no upthrust, and the metal should freeze in the vertical joint.

In ordinary uncooled furnaces, if 6 ft. of carbon is the correct thickness for an 18-ft. furnace, then a 9-ft. thick hearth should be used on a 27-ft. dia. furnace to give the same temperature distribution.

Mr. **C. Danielsson** (Domnarfvets Iron and Steel Works, Sweden) : The use of a carbon-brick lining in a blast-furnace has a great advantage, if the bricks are sufficiently durable. Well before the last war, carbon was successfully used in Germany for the bottom, hearth walls, and bosh. The use of carbon in the stack is, however, new.

In Domnarfvet, our research department, under the direction of Professor Kalling, investigated the composition and temperature of the gas at the walls of a furnace lined in the ordinary way with firebrick. No coolers were used. If the actual CO content is less than that at equilibrium then the equation $C + CO_2 \rightleftharpoons 2CO$ will proceed from left to right and carbon will go into solution (*see* Table A). The

* J. Taylor, *J. Iron Steel Inst.*, 1950, vol. 164, pp. 129–140.

† L. M. Fulton, *Proceedings of the Blast Furnace and Raw Materials Conference*, 1950, vol. 9, p. 280.

carbon-brick temperature at the inwall side must therefore be kept sufficiently low.

This explains why comparatively good results have been obtained in Britain using cooled furnaces with carbon bricks in the walls. Cooling can be accomplished by spraying with water, without insulation or by insulating the furnace to save the shell. Insulation must be accompanied by wall cooling, otherwise the stack lining will have a very short life.

Dr. **T. P. Colclough,** C.B.E. (British Iron and Steel Federation) : Our American friends have made great progress in blast-furnace refractories in the past 20 years. Between 1930 and 1932, the newly designed high efficiency stoves, with their relatively high temperatures, suffered severely from contraction of the checker work. The same difficulty was later experienced in Germany where two stoves, built for unusually high temperature conditions, showed a contraction of about 2 m. in the height of the checker work.

In 1932, I issued a specification for the bricks to be used in a new blast-furnace plant in which the after-contraction was specified as not more than 0·1%, which in practice means nil, and today blast-furnace bricks are available with almost no volume change on prolonged exposure to high temperatures.

Mr. Rice is correct in his diagnosis that we in Britain do not blow our blast-furnaces sufficiently hard. Most of the early turbo-blowers installed were designed with a maximum operating rating of about 20 lb./sq. in., but new blowers are being designed for a pressure of 35 lb./sq. in.

In regard to the Rice rating, Scott-Maxwell and I, in a paper* on the trends in blast-furnace design, agreed that the capacity of blast-furnaces should be calculated on the area of the tuyere annulus, but we did not accept the Rice rating which specifies the weight of coke that can be burned per minute on each square foot of this annulus.

I believe that the rate of coke combustion given by the Rice rating is too high for efficiency. Those furnaces in America which approach the Rice rating of 100% are not in equilibrium and those at 105% and 110% are still further from equilibrium ; the Dutch furnace, which is given a rating of 119%, seems to be the furthest from equilibrium. In this country the coke rate is more critical than the production figure. Assuming a CO/CO_2 ratio of 2 : 1 as given by Austin,† the figures given by Mr.

* I. S. Scott-Maxwell and T. P. Colclough : *J. Iron Steel Inst.*, 1948, vol 159, pp. 186–192.

† J. B. Austin, *J. Iron Steel Inst.*, 1951, vol. 167, pp. 358–363.

Table A

ACTUAL AND EQUILIBRIUM COMPOSITION OF GAS SAMPLES AT THE INWALL OF NO. 5 FURNACE

Test No.	Sample No.*	Actual Gas Composition		Temp., C.	$\frac{CO}{CO+CO_2}$ actual, %	$\frac{CO}{CO+CO_2}$ equilibrium, %	Diff., %
		CO_2, %	CO, %				
1	I	8·0	33·2	...	80·6	...	...
	II	0·0	37·8	1072	100·0	100·0	0·0
	III	0·4	40·3	1005	99·0	100·0	−1·0
	IV	0·2	37·9	969	99·5	99·5	0·0
	VI	0·0	37·4	1112	100·0	100·0	0·0
	VII	0·0	37·0	1202	100·0	100·0	0·0
2	I	6·2	35·5	...	85·1	...	...
	II	0·2	38·4	1012	99·5	100·0	−0·5
	III	0·6	40·2	1030	98·5	100·0	−1·5
	IV	0·5	38·8	1023	98·7	100·0	−1·3
	VI	0·0	37·4	1129	100·0	100·0	0·0
	VII	0·0	37·4	1169	100·0	100·0	0·0
3	I	7·2	33·4	...	82·3	...	...
	II	0·4	38·0	1002	99·0	100·0	−1·0
	III	0·6	37·8	1032	98·4	100·0	−1·0
	IV	0·4	37·7	960	99·0	99·5	−0·5
	VI	0·0	39·2	1202	100·0	100·0	0·0
	VII	0·3	38·8	1198	99·2	100·0	−0·8†
4	I	...	...	...	...	...	...
	II	0·8	39·2	997	98·0	100·0	−2·0
	III	0·6	40·8	1001	98·6	100·0	−1·4
	IV	0·2	37·8	1002	99·5	100·0	−0·5
	VI	0·0	36·8	1028	100·0	100·0	0·0
	VII	0·0	37·0	1071	100·0	100·0	0·0
5	I	9·6	32·4	611	77·1	36·0	+41·1
	II	3·0	35·6	930	92·2	99·0	−6·8
	III	0·0	39·5	988	100·0	100·0	0·0
	IV	0·4	37·8	1032	99·0	100·0	−1·0
	VI	0·0	35·7	1108	100·0	100·0	0·0
	VII	0·0	36·0	1206	100·0	100·0	0·0

* Sample I was taken about 1 m. below the stockline, and the following samples at 1-m. intervals. No sample V could be taken because of bad wall condition.
† Air leakage.

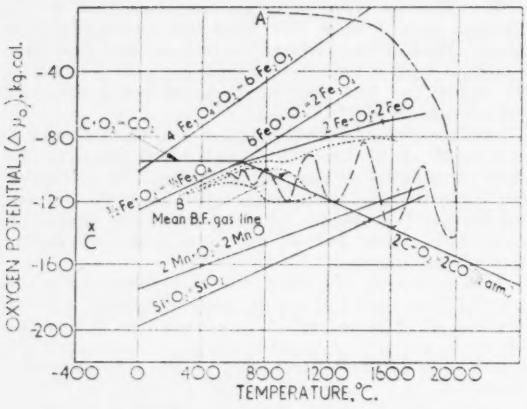

Fig. B—Oxygen potentials in the blast-furnace

Rice (Table V) can be compared with the standard rate set up 15 years ago (and since improved) on the basis that the carbon consumption of a blast-furnace should be 1300 lb./net ton for the metal plus 0·3 times the weight of the slag. Only about six of the furnaces listed by Mr. Rice show a higher coking rate than that corresponding to the standard consumption rate. We know from experience that even on lean-ore burdens we can improve on a ratio of 2 : 1, and I am convinced that if our British blast-furnaces are driven at the Rice rating, it will only be at the expense of the coke rate and of the price of the pig iron.

Dr. **F. D. Richardson** (Nuffield Research Group in Extraction Metallurgy, Royal School of Mines) : It has been asked why carbon linings survive in the stack, when the blast-furnace is a great consumer of carbon in the form of coke. A pointer to the explanation may be found in Fig. 4, of a paper by Jeffes and myself,* which illustrates oxygen potentials in the blast-furnace. Figure B is a modified version of this figure. The dotted lines (B.F. gas lines) represent the oxygen potentials corresponding to the CO/CO_2 ratios reported for samples of B.F. gas, which were obtained by the Blast-Furnace Reactions Sub-Committee. Fuller details are given in our paper. The middle line represents the mean of all the reported ratios, and the other two represent the upper and lower extremes.

If the oxygen potentials of the furnace gases lie on or below the C–CO line given in this figure, there will be no attack on the carbon lining. Thus, if all the gas had the average composition, there would be danger of attack only at temperatures between 1100° C. and 800° C. In general, however, the stack walls will be 50° or even 100° C. cooler than the gases, and the temperature of gases directly in contact with the walls will be correspondingly reduced.

The effect of this will be to lower the oxygen potentials (for the same CO/CO_2 ratios) by shifting them 50° or 100° towards the point *C*. Such a shift will bring the average line, even in the range 800–1100° C., to or below that for equilibrium with carbon (C–CO line), so that 'on the average' the walls will be safe. The maximum and minimum values will be shifted correspondingly, but most of the maximum values will remain above the C–CO line. To explain why the walls do not dissolve in the gases it is therefore necessary to assume either that the puffs of gas of different oxidizing and reducing compositions follow one another more quickly than the carbon refractories can react to them, or that any carbon lost on contact with a puff of highly oxidizing gas is immediately replaced, in the same position, by a following puff of reducing gas.

Reaction between solid ore and the carbon refractories must also be considered. Ore which touches the walls must be in contact with any particular piece of carbon refractory for a few seconds, so that direct reaction between these two solids must be too slow to be of any significance.

The diagram given in our paper shows that a large drop in temperature at the walls is desirable to preserve the carbon refractories ; the thermal conductivity of the carbon refractories, which is four or five times that of firebrick, may be of great value in this respect. Attempts to offset the heat loss so caused, by improved insulation, might possibly lead to disaster.

CORRESPONDENCE

Dr. **K. J. Irvine** (Leeds University) wrote : Because of the nature of the ore deposits in the U.S.A., extensive grinding has to be carried out before concentration can be effected. Whatever concentration methods are used the particle size is getting smaller. Figures of down to 100 mesh for marginal ore treatment, 200 mesh for tailing retreatment processes, and 300 mesh for the taconite treatment, can be quoted as typical. Important changes in blast-furnace practice are likely to follow the agglomerating developments now taking place. These developments will be of world-wide interest while the trend to lower-grade ores continues. The magnetic taconites, as agglomerated, are hard, readily reducible, contain 65% of iron, and are conveniently shaped for optimum packing. However, the cost of grinding and then agglomeration is high. Is it not possible that something might be accomplished with this finely divided iron ore ? Such a fine particle size may be unattractive when considering the gas–solid reaction in the blast-furnace, but apart from this the fine particle size is very desirable. It may be possible to reduce iron ores by fluidization techniques such as have been introduced into other industries.

Further information on hot-blast temperatures would be welcome. Although, in general, American furnaces are limited by the reduction rate, some of the recent changes that affect the rate of reduction, *e.g.*, ore preparation, elimination of fines, and utilization of sintered material, or high-pressure operation, should influence the hot blast temperature. Although Mr. Rice indicates that the position has changed only slightly during 40 years, reference to a paper by Haven† suggests that the position has in fact become worse.

Haven says that "By the combined effects of better furnace lines and better materials, it is probable that the blast temperatures carried today are about 20% higher than they were ten years ago. In practice with Lake ores they probably average about 1250° F. When considerable quantities of coarse materials are available, or when it is possible to practice slow blowing, from 1350° to 1500° is not unusual and as high as 1600° has been reported." Is this change due to smaller quantities of coarse ore

* F. D. Richardson and J. H. E. Jeffes, *J. Iron Steel Inst.*, 1949, vol. 163, pp. 397–420.

† Wm. A. Haven, *J. Iron Steel Inst.*, 1933, No. I, p. 72P.

being available, greater utilization of fine concentrates, or can any other explanation be given ?

I should be grateful also for the present American view on hot-blast drying. Undoubtedly local climatic conditions affect the situation very much, but published reports of installations and the benefits obtained are often conflicting. Has any great advantage been obtained from the uniformity of blast moisture obtained, or do the small variations in heat produced in the tuyere zone have little effect on a furnace governed by rate of reduction ?

Mr. **J. Corke** (Dorman Long and Co., Ltd.) wrote : Mr. Ridgion states that coke quality, ore grading, blast temperature, slag volume, slag fusion, and hanging of the materials inside the blast-furnace can account for the coke-burning rate. The core in Fig. A indicates that ore grading is one of the most important items whereby the rate of drive can be increased. It has been stated that fines up to $\frac{1}{2}$ in. in size must be removed. We could not possibly agree to this size when dealing with Swedish ore.

I think the most important points after ore grading are slag fusion and slag volume. In America there are not many furnaces working with an alumina content in the slag above 14%, whereas we are working with 18–23%. The type and amount of slag made plays a very important part in determining the coke rate and the coke burnt. If we could reduce the alumina content by adding a synthetic material and thus lower the melting point of the slag, we might work at more than 78% of the Rice rating.

Dr. **D. W. Gillings** (Central Research Establishment, National Coal Board) wrote : Mr. Rice elaborates on his theoretical treatment of the rate of operation of a furnace in terms of the rate of combustion of coke, and has developed the concept as a method of assessing furnace performance. Increase of oxygen in the blast increases flame temperature and hence increases the rate of combustion of coke. This effect is observed by an increased rate of production of ferro-manganese in the author's experiments. As stated by Mr. Rice, it is not generally possible to take advantage of the increased flame temperature in basic practice. It is necessary to differentiate between furnaces and furnace practices in which high blast temperatures are acceptable (and presumably in which enriched blast would be advantageous), and those in which factors other than combustion limit furnace output. If such limiting factors could be removed, full advantage could be taken of the high-temperature or enriched blast. The optimum conditions for the use of the potential value of enriched blast need investigating.

Mr. **J. H. Patchett** (Dorman, Long and Co., Ltd.) wrote : The coke rate of 1762 lb. for the northern furnaces given in the paper by Mr. Rice appears to be high, compared with the slag volume of about 1000 lb. given in Table II. The coke quality (ash 9·8–10·5%, sulphur 0·9–1·02%) does not account for such a high coke rate. These furnaces are therefore driven at an uneconomical rate.

In British practice the desirability of obtaining the lowest possible coke rate is of paramount importance, mainly because of the relatively high cost of coke and the limited supply. With a slag volume of 1000 lb., a coke rate of 1500 lb. should be aimed at by careful preparation of the burden and sizing of the coke. Furnace 9 (*see* Table II) almost attains this performance with a rating of 90·1%. It would be interesting to have more information about the type of burden, the degree of preparation of the burden, and coke quality used in this furnace. The author's explanation of the lower coke rate would be valuable.

The absence of after-contraction in the American refractories renders them suitable for the building of furnace hearths. With such material laid with close joints and adequate cooling (face-to-face contact of the cooling member with the brickwork), breakouts should be avoided.

Freedom from breakouts cannot be assured with any material unless contact between masonry and the cooling surface is good. The use of carbon for hearth construction does not lessen the necessity for a cool surface sufficiently close to the working face of the hearth to avoid softening and erosion followed by a breakout.

The author's suggestion that methods should be adopted for a further improvement in thermal conductance between metal jacket and refractory wall could be met by building a double steel hearth jacket with cooling pipes inserted between the two plates, bedded in with carbon ramming. Carbon ramming could also be used to give the necessary contact between the inner steel jacket and the refractory hearth brickwork. If a construction of this type were adopted, using American firebrick free from after-contraction, the risk of blackouts would be reduced to a minimum.

Dr. **T. P. Hoar** and Dr. **D. V. Atterton** (Cambridge University) wrote : In the paper by Chesters, Elliot, and Mackenzie, it is stated that molten slag and metal penetrate fireclay-brick hearths of blast-furnaces because they wet fireclay relatively easily. We agree that the slag penetration is aided by such wetting, but believe that the metal penetration must be caused by metallostatic pressure. We have shown* that molten metals do not wet silica, moulding sand, and powdered alumina—if they did sand casting would be impossible. We think it may be inferred from our experiments, and from the fact that metals may be cast in powdered fireclay (chamotte), and from general physical theories of adhesion and cohesion, that they do not wet fireclay.

The metal head necessary to force molten iron or steel into compacted moulding sand of average mesh is about 35–110 cm.* The permeability given by the authors for the fireclay bricks is of the same order of magnitude as the permeability of typical moulding sands ; if the permeability is taken as a very approximate guide to the pore size, then the head necessary to force molten pig iron into the fireclay bricks should be about 25–80 cm.—these lower values result from the considerably lower surface tension of pig iron compared with that of iron or steel. The No. 10 blast-furnace described by Chesters and his co-workers provides a metal head of about 5 ft. ; this alone should be sufficient to cause metal penetration of the bottom bricks and the bottom 2 ft. of the side bricks of the hearth. We suggest that the lack of penetration into graphite bricks results from their very much smaller pore size, and from the fact, demonstrated by the authors, that neither slag nor metal wets graphite.

AUTHORS' REPLIES

At the time of going to press no reply had been received from Mr. Rice.

Mr. **Chesters**, Mr. **Elliot**, and Mr. **Mackenzie** wrote in reply : Several speakers appear to have thought of a hearth with carbon walls and a fireclay bottom and there may be advantages in such a construction if the

* T. P. Hoar and D. V. Atterton, *J. Iron Steel Inst.*, 1950, vol. 166, p. 1.

removal of carbon from the bottom cannot be prevented. With such a construction, the essential feature of the deep water-cooled carbon chimney, built independently of the bottom, would have to be preserved. Cooling below the hearth must be given a trial. Another idea to improve the life of the bottom bricks, for those who favour fireclay, is to step out carbon bricks from the water-cooled walls to below the centre of the fireclay hearth. In this way the improved cooling through the carbon should raise the 'freeze line' in the bottom.

Mr. Voice's calculations are of special interest and the figures quoted are similar to those obtained by Appleby-Frodingham in designing an air-cooled hearth. The use of long hexagonal blocks is open to dispute—serious difficulties are likely to arise in maintaining the consistent high quality of carbon in a large shape.

Mr. Danielsson rightly points out the importance of gas composition and that each practice must be considered separately. If the gas is of a composition that will oxidize carbon, then insulation of the lining will be dangerous. Dr. Richardson's suggestions will be examined in regard to typical Appleby-Frodingham data. It still does not seem possible for all to agree on why carbon bricks remain in the stack.

The explanation of iron penetration given by Dr. Hoar and Mr. Atterton may well be the correct one. There is no doubt that iron will penetrate into fireclay much more readily than into carbon and, in general, the permeability of carbon bricks is much lower than that of fireclay. In one case examined at Appleby-Frodingham, iron had passed through the joints between carbon bricks without penetrating into them, but had completely soaked a good-quality fireclay brick underlying the carbon.

The Joint Discussion on the papers "Full-Scale Blast-Furnace Trials," by J. A. Bond and T. Sanderson, and "Distribution of Materials in the Blast-Furnace," by R. Wild, will be published in the March issue of the *Journal*. Owing to the indisposition of one of the authors a reply was not received in time to publish the discussion in this issue.

CORRESPONDENCE ON PAPERS

Correspondence on the Paper—

WORKS TRIAL OF A METERING PUMP

By A. L. Cude and J. Stringer *

Mr. **E. M. Noyes** (Viniyl Products, Ltd., Carshalton) wrote: I would like to comment on the equipment used by the authors, although I realize that the alternatives I suggest may not have been applicable under local circumstances, or suited to a temporary installation for a test of short duration.

In furnace operation, the purpose of the metering pump and of its speed control is clearly to avoid any rapid fluctuation of the oil delivery to the furnace that might result from changes of load, viscosity, voltage, or supply frequency. Such fluctuations might delay or damage the furnace, and would reduce its thermal efficiency. This applies particularly to manually controlled furnaces; with automatic control, the variation could be corrected immediately by the combustion regulator, or more slowly by the temperature controller.

Slow changes over a period of time are of little importance with manually controlled furnaces, as the melter must always pay close attention to the flame. The only real risk is over-confidence in the uniformity of the supply.

I would therefore suggest the use of a synchronous motor to drive the pump. The speed of these motors is dependent only on supply frequency, which, in Works connected to the Grid, changes only slowly and over a narrow range. Even in Works with an independent system, when the generating plant and its load conditions are favourable the variation may be tolerable, as the better turbine governors are usually accurate to $\pm 2\frac{1}{2}\%$. At present the Grid frequency† is not permitted to fall below 48 cycles (-4%) at peak periods, or rise above 50·7 cycles ($+1{\cdot}4\%$) in catching up periods; at other times it is controlled to $\pm \frac{1}{20}$ cycle ($\pm 0{\cdot}1\%$). I suggest that as the changes occur slowly these limits are permissible, although they are outside those proposed by the authors. Moreover, the simplicity of a synchronous motor, compared with an electronic or other speed regulator, is a definite advantage.

Other methods proposed to achieve the same result are:

(i) Pressure regulation of the oil by a reducing valve before the furnace stop valve
(ii) Flow control of the oil by controlling meter, adjusted manually or by the combustion/temperature regulator group
(iii) Combustion regulation, taking the air meter as the leading member and the oil as the follower in thermostatic systems. The air flow is least subject to extraneous disturbance. Air leaks occurring beyond the meter do not matter, from this point of view, as the actual, not theoretical, combustion ratio is determined by inspection. Differences between ends are common to all systems.

Data on the relative merits of these methods might be of value in plant design and selection.

On the question of oil filtration, I would draw the authors' attention to the merits of centrifugal separation. This is referred to[1] in connection with heavy marine oil engines operating on non-distillate fuels.

AUTHORS' REPLY

Mr. **Cude** and Mr. **Stringer** wrote in reply: When planning the metering pump trials, two sources of error had

† Information supplied by B.E.A. Public Relations Department, Kingston Power Station.

* *J. Iron Steel Inst.*, 1951, vol. 168, May, pp. 46–51.

to be considered: variation in motor speed, and any errors in the pump itself. The main object of the test was to determine the latter errors, and special equipment was therefore installed to keep the pump speed as nearly constant as possible. The inherent accuracy of the pump has proved to be high,[2] so that in most practical applications some latitude in speed control would be permissible. We agree with Mr. Noyes that, in most cases, a synchronous motor would be adequate and would have the added advantage of reducing the cost of the pump unit to compare favourably with conventional flow controllers.

Concerning the alternative methods of flow control suggested, we would point out that pressure control (method (i)) is, in effect, generally used, since the ring main pressure is controlled by a reducing valve on the return flow. This method is quite ineffective, the normal error taking the form of a persistent reduction in flow which may be due to the building up of colloidal matter on the control valve. Other complications, at least on open-hearth furnaces, are due to temperature variations in the relatively long furnace branch lines, and to interaction with the steam pressure in the inside mixing burners which so far have proved most suitable for this type of furnace.

All other methods of flow measurement and control make use of the pressure drop across an orifice. Because of the relatively high viscosity of oil, this pressure drop can be kept at a reasonable value only by operating at a low Reynolds Number, where the discharge coefficient of the orifice is sensitive to changes in the viscosity and density of the oil. This type of error, which was discussed by Stringer[3] and was shown to be of considerable magnitude, is added to the inherent error of the instrument, which is usually quoted by the manufacturers as within $\pm$ 2% of full flow at all flows; it is therefore proportionately greater at lower flows. In the metering pump, where the error is mainly due to speed variation, it is a constant fraction of the actual flow, so that in the lower flow ranges the pump should be much more accurate than the orifice meter.

The metering pump itself did not show any adverse effects that could be ascribed to dirt in the oil. The difficulties encountered were confined to the ancillary gear, and were probably due to faults of installation and operation which can be avoided in future. As far as can be judged from this limited test, the standard of cleanliness of oil supplied by the major oil companies is adequate, and there is no justification for expensive centrifugal cleaning.

REFERENCES

1. W. H. Purdie: *Proc. Inst. Mech. Eng.*, 1950, vol. 162, No. 4, p. 454.
2. J. Stringer and A. F. Gay: *J. Iron Steel Inst.*, 1949, vol. 163, pp. 71–80.
3. J. Stringer: *Ibid.*, pp. 168–172.

Correspondence on the Paper—

THE OXYGEN LANCE IN ELECTRIC FURNACE PRACTICE—Part II

*By W. H. Everard and D. J. O. Brandt**

Dr. **D. D. Howat**: (The Royal Technical College, Glasgow) wrote: The main factor in the paper is the influence of temperature on the relative rates of oxidation of carbon and chromium. Although reaction rates are not easy to measure, an indication of the effect of temperature may be obtained from the equilibrium constants. Presumably the first result of blowing oxygen through the bath of molten steel is the production of FeO in solution. This FeO in solution in the metal then reacts with the different constituents of the bath. Possible reactions are:

$$FeO + C = Fe + CO \quad \ldots\ldots(1)$$
$$2FeO + Si = 2Fe + SiO_2 \quad \ldots\ldots(2)$$
$$FeO + Cr = Fe + CrO \quad \ldots\ldots(3)$$
$$FeO + Mn = Fe + MnO \quad \ldots\ldots(4)$$

The equilibrium constants for these reactions may be expressed in simplified form as:

$$\text{Reaction (1)} \quad \ldots \quad K_C = \frac{1}{[FeO][C]}$$

$$\text{Reaction (2)} \quad \ldots \quad K_{SiO_2} = \frac{[SiO_2]}{[FeO]^2[Si]}$$

$$\text{Reaction (3)} \quad \ldots \quad K_{CrO} = \frac{[CrO]}{[FeO][Cr]}$$

$$\text{Reaction (4)} \quad \ldots \quad K_{MnO} = \frac{[MnO]}{[FeO][Mn]}$$

Values for K_C, K_{SiO_2}, and K_{MnO} are available in the literature, but the value for K_{CrO} has been obtained by combining K_C with the constant K_{Cr} derived by Hilty for the reaction $CrO + C = CO + Cr$, for which $K_{Cr} = \frac{[Cr]}{[CrO][C]}$. Thus $K_{CrO} = \frac{K_C}{K_{Cr}}$.

The variation of the equilibrium constants with temperature is plotted in Fig. A for each of the reactions. A rise in temperature effects a very marked decrease in the value of the equilibrium constants for reactions (2) and (3), the decrease being very much greater than that for reactions (1) and (4).

The effect of higher temperatures on the equilibrium constants for the oxidation of chromium and of manganese by FeO may also be expressed by the ratio of the metal oxide to the residual metal in the bath at any given temperature. For this purpose it has been assumed that the FeO content of the bath is determined only by the carbon content, in accordance with reaction (1), and is not affected by the presence of other alloying elements. On this assumption, the required ratios are:

$$\frac{CrO}{Cr} = K_{CrO} \times FeO, \text{ and } \frac{MnO}{Mn} = K_{MnO} \times FeO.$$

Values of the FeO content of the bath have been calculated for carbon contents of 0·05, 0·10, and 0·15%, at various temperatures, and values obtained for the ratios are as follows:

Temperature, °C.	Carbon Content, %	CrO/Cr	MnO/Mn
1550	0·05	1·476	0·127
	0·10	0·741	0·064
	0·15	0·494	0·043
1600	0·05	0·893	0·110
	0·10	0·447	0·055
	0·15	0·278	0·037

* *J. Iron Steel Inst.*, 1950, vol. 165, pp. 411–418.

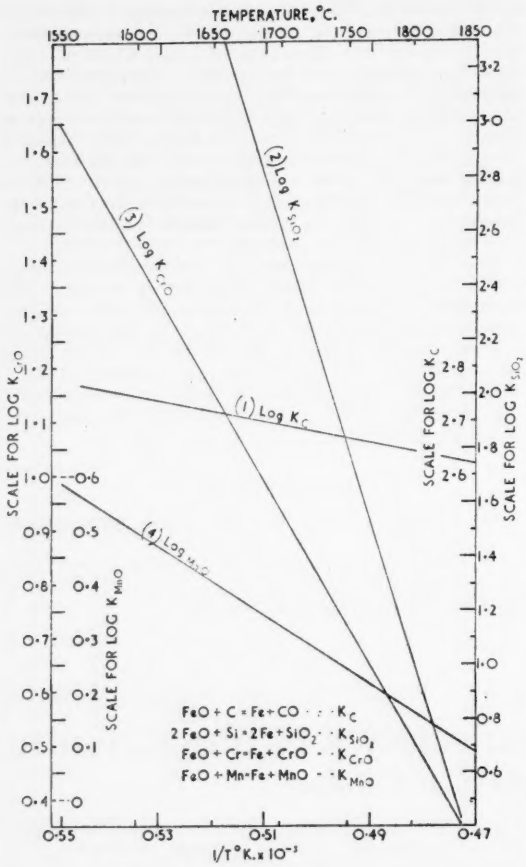

Fig. A—Variation, with temperature, of the equilibrium constants for the reactions (1)–(4)

Temperature, °C.	Carbon Content, %	CrO/Cr	MnO/Mn
1650	0·05	0·550	0·095
	0·10	0·275	0·048
	0·15	0·184	0·032
1700	0·05	0·347	0·084
	0·10	0·174	0·042
	0·15	0·116	0·028
1750	0·05	0·214	0·074
	0·10	0·102	0·037
	0·15	0·071	0·024
1800	0·05	0·148	0·066
	0·10	0·074	0·033
	0·15	0·049	0·022
1850	0·05	0·100	0·059
	0·10	0·050	0·029
	0·15	0·033	0·019

The most noticeable feature of these results is that at 1850° C. the ratio CrO/Cr is reduced to about 0·07 times its value at 1550° C. whereas the ratio MnO/Mn is reduced by only about one half. In view of the very rapid decrease in the value of CrO/Cr over this temperature range, it is obviously essential to raise the temperature of the bath as rapidly as possible to the higher temperatures, and the heat required for this purpose may conveniently be obtained by oxidation of the carbon, silicon, manganese, chromium, and iron, present in the melt.

The quantities of those elements oxidized may be estimated roughly for the ten melts by averaging the figures given in Tables VII and VIII of the paper. An estimate of the quantities of iron oxidized may be obtained from the figures for the slag composition of melt *A6*, given on p. 417. For the slag formed during the first period of blowing, the iron content is 5·15% and the weight of the slag is 807 lb. The iron content of the slag formed during the second period of blowing is 4·87%, and the slag weight is 1635 lb. Expressing the iron content in terms of FeO, the weight of FeO is 53·4 lb. in the first slag and 102 lb. in the second slag, giving a total weight of 155·4 lb. of FeO formed, corresponding to an oxygen consumption of 34·5 lb.

Taking average figures over the 10 heats, the following information is obtained :

Element	Quantity Oxidized, lb.	Quantity of Oxygen Required, lb.	Heat Liberated, kg.cal.
C	8·35*	12·28	10,460
Si	35·40*	40·30	123,500
Mn	26·55*	7·73	16,370
Cr	331·0*	153·0	395,000
		213·31	545,330
Fe	121·2†	34·5	54,800
Total		247·81	600,130

* From Tables VII and VIII of the Paper
† Calculated

Average oxygen blown per melt = 3616 cu. ft. = 322 lb.

From these figures it will be seen that the efficiency of oxygen utilization with reference to carbon, silicon, manganese, and chromium, is 66·2%, and that the overall efficiency of oxygen utilization is 247·8 lb. out of a total of 322 lb., *i.e.*, 76·8%. The oxidation of chromium provides 65·7% of the total heat generated in the bath by the oxygen supplied. The amount of oxygen available to combine with iron is 108·7 lb., which is equivalent to 381 lb. of FeO and is greatly in excess of the quantity actually formed, as calculated from the slag analyses given on p. 417. The statement (p. 416) that " between a quarter and a half of the total volume of oxygen blown is consumed in the oxidation of iron " therefore appears to need a little clarification, as, according to the calculations set out here, it would appear that about one quarter of the total oxygen blown escaped uncombined from the bath. Can the authors offer any suggestions on this point ?

AUTHORS' REPLY

Mr. **Brandt** wrote in reply : We agree with Dr. Howat that, with the data available at present, there is by no means a perfect ' tie-up ' between metal and slag analyses, probably because the metal analyses given represent the average of ten heats whereas the slag has only been assayed on one occasion (heat *A6*). It is not justifiable to attempt a materials balance on the lop-sided evidence that we have here. Very possibly some more slag analyses would indicate that, in fact, between a quarter and a half of the oxygen *has* been used in the formation of oxides of iron, in which case the iron content of the slag after the second blow would be higher than that shown, and the anomalous behaviour of the slag iron during reduction with ferro-silicon would no longer be recorded. Unfortunately, these slags are not easily dealt with in a routine laboratory, and the data have not yet been collected.

Apart from this, there is the possible loss of iron as iron oxide fume. However, although this often appears serious, there is evidence to indicate that it is generally not nearly so bad as its apparent density would suggest.

B. I. S. R. A.

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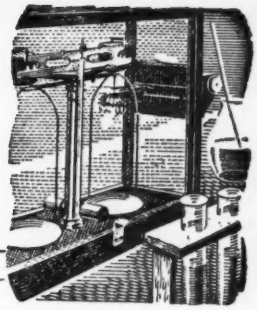

Measurement of Air Infiltration in Open-Hearth Furnaces

By R. Haynes, B.Sc.

SYNOPSIS

The paper describes the direct measurement of air flow, in furnace uptakes and in the culverts below the checkers, using a water-cooled Pitot static tube. Generally, infiltration is found between the culverts and uptakes at low air flows, and air is lost between them when the fan speed is high.

BECAUSE of the high operating temperatures of open-hearth furnaces the entry of cold air must be avoided to attain the greatest efficiency, except when a controlled amount of excess air is permissible for metallurgical purposes.

In many plants, metering, coupled with automatic control or vigilant manual control, is sufficient; in regenerative furnaces the problem is not so simple. Orifice or venturi meters can be fitted at the point of air intake but the air has to pass through brick ducts, reversing valves, and regenerators. However high the standard of maintenance, these passages and valves are never completely air-tight.

Unless leaks can be effectively stopped, the air flow at the furnace port, as well as at the point of entry to the furnace system, must be known.

Since it is seldom practicable to run a furnace with a positive pressure at all levels, excess air enters the working chamber through the doors and similar openings. Recent work on model furnaces[1] shows clearly that this excess air can be controlled by the furnace damper. In the present paper means of measuring the air that reaches the combustion ports are discussed. This would be a guide to correct control of the initial air/fuel ratio irrespective of the excess air that enters the melting chamber later.

Methods of Measurement

The first direct measurement of air and waste-gas flow in furnace uptakes was apparently made in 1939.[2] Traverses were made using a water-cooled Pitot tube of N.P.L. pattern and the flow calculated from contours of equal velocity constructed from the data collected. Some years before this, however, Kofler and Schefels[3] had used a straight water-cooled Pitot static tube to measure gas velocities inside an open-hearth furnace chamber.

Suggested alternatives to the Pitot-tube methods of measurement include:

(i) Hot-wire anemometer or heat transfer between two electrical grids
(ii) Orifice or venturi measurements
(iii) Sonic methods.

Whereas a hot-wire anemometer is suitable for the range of velocities encountered it cannot be used inside a furnace. Heat-resisting orifices or venturis would involve difficult bricklaying, and their dimensions would soon be changed by erosion or build-up of the slag particles carried in the waste gases. An orifice would upset the furnace characteristics, and would also bring about a small permanent pressure drop which would be undesirable in this type of furnace.

It is possible that some of the sonic methods may be suitable, but much further work is required to find a suitable technique.

For the present work a water-cooled Pitot static tube was considered to be the best practical method.

EXPERIMENTAL PROCEDURE

The measurements were made in the uptakes of open-hearth furnaces near the actual combustion port, yet easily accessible from outside. A similar point of measurement could be used in other types of regenerative heating furnace.

The water-cooled, round-nosed, N.P.L. tube used by Leckie[2] was unsuitable as a diameter of 2 in. was necessary to accommodate sufficient cooling water,

Paper SM/AA/33/51 of the Open Hearth Instruments Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 16th July, 1951.

Mr. Haynes is Head of the Industrial Experimentation Section of the Division at Sheffield.

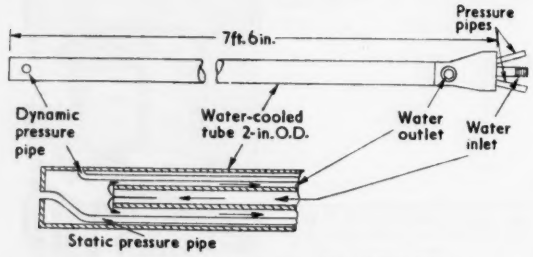

Fig. 1—Straight water-cooled Pitot tube.

and an N.P.L. tube of this diameter would need an excessively large hole in the furnace for manipulation. A straight water-cooled type (Fig. 1) was therefore built because it required only a 2-in. dia. hole in the uptake wall. This tube is rather similar to that used by Kofler and Schefels[3] but with the pressure holes better sited in relation to the tip of the tube. In this type of tube the dynamic hole should be at least 0·5 of the tube diameter from the end; this was not the case with the German tube.

Each survey of a cross-sectional area had to be completed within one reversal for it could not be assumed that the air flow would remain constant from one reversal to the next. This limited the number of points obtainable and therefore the accuracy of the method. However, with experience the number of points was increased to nearly six times the number obtained in the early trials.

During this early work the pressure differences produced by the Pitot tubes were measured with a null deflection micromanometer but, although this was accurate, considerable delay occurred because the instrument had to be reset every time a pressure difference was applied to it. Kent slant gauges were therefore used subsequently, and similar gauges of even greater sensitivity were constructed in the B.I.S.R.A. laboratories for use in the latest work.

A mean value of flow was obtained from Pitot-tube readings by planimetering the areas between equal-velocity lines. The flow patterns reconstructed from 'spot' readings obtained during typical Pitot-tube traverses are shown in Fig. 2. The readings were taken at distances of not more than 8 in. apart.

Difficulties Encountered

The investigations were complicated because the Reynolds Number of a Pitot tube sited in an open-hearth furnace uptake, being extremely low, is in the critical range. Reynolds Number is defined as $\rho dv/\mu$, where ρ = the density of the fluid, v = the velocity of the fluid, d = the diameter of the obstruction, and μ = the absolute viscosity of the fluid, all the variables being expressed in self-consistent units.

The Pitot-tube coefficient may vary sharply in this critical region and it is vital to know how this variation is related to the Reynolds Number, which depends, among other things, indirectly on the temperature of the air stream. This temperature must be measured accurately and preferably continuously because it will decrease steadily during each survey. Accurate temperature measurement will also be needed for computing the velocities from the Pitot differentials, and reducing the velocities to N.T.P. to enable comparisons to be made with the air-meter reading.

Slag attack on the Pitot tube is not so serious when measuring the air flow as when measuring waste-gas velocities, particularly if the tube is water-cooled.

A further complication is the unevenness of flow encountered in furnace uptakes, which, in bad cases, may necessitate preliminary flow-pattern studies.

Sources of Error

The present trials included an investigation into the following possible sources of error:

(i) The lack of accurate knowledge and possible lack of consistency of the coefficient of the Pitot tube used
(ii) The local effect on the flow pattern of using a water-cooled tube in a very hot gas stream
(iii) The method of calculating the flow in the uptake from individual Pitot readings although the flow may be fluctuating and unevenly distributed
(iv) The effect of angle of yaw and angle of pitch on the Pitot-tube coefficient.

Experiments in a specially constructed cold wind tunnel showed that a reasonably stable coefficient for the Pitot tube could be obtained over the range of Reynolds Numbers from 400 to 3750.

Differences between cooled and uncooled Pitot tubes, when placed in a hot gas stream, were studied in a separate experiment. A large scatter existed in the results and, although a statistical examination showed a small significant difference between the two tubes, it was decided not to apply a correction until further experiments could be made in a hot wind tunnel. This has yet to be constructed.

The accuracy and reproducibility of the Pitot-tube technique was checked in a furnace uptake and a cold wind tunnel. The total error involved was found to be less than 3% and it was considered that this demonstrated the degree of reliability of the method.

The effects of angle of yaw and angle of pitch on the Pitot-tube coefficient were studied in the cold

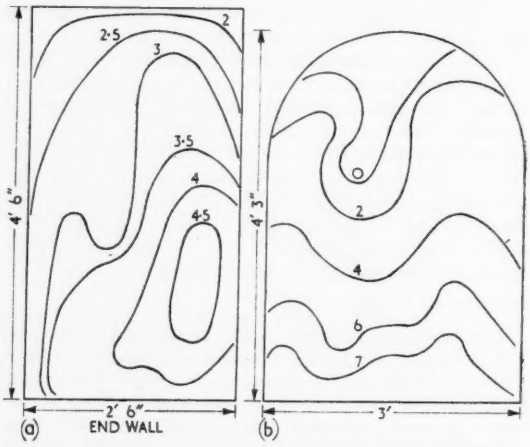

Fig. 2—Typical flow patterns showing stratification of flow (*a*) in furnace uptake, (*b*) in furnace culvert. (Figures on contours are velocities in ft./sec. at N.T.P.)

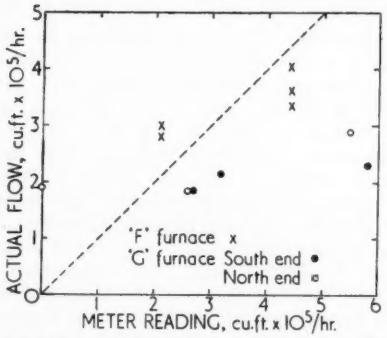

Fig. 3—Relationship between actual and metered air flow in furnaces at Shelton Iron, Steel and Coal Co., Ltd.

wind tunnel. It was found that variation in angle of yaw had far more effect than that of pitch. A 10° angle of pitch (with zero yaw) gave a variation in the coefficient of less than 2%.

EXPERIMENTAL RESULTS

Four determinations are reported below: two were carried out at the Shelton Iron, Steel and Coal Co., Ltd., one at Messrs. Samuel Fox and Co., Ltd., Stocksbridge, and one at the Briton Ferry Steel Co., Ltd.

Work at Shelton

These experiments were carried out on *F* and *G* furnaces.* Temperatures were measured with an optical pyrometer and corrections applied according to comparisons previously made with a suction pyrometer. Pressure differences were measured with a null deflection micromanometer, seven readings being made during each reversal.

For the experiments on *F* furnace, which can be regarded as being of a preliminary character, only one Pitot tube was available. Thus it was only possible to measure the air flow in one uptake at a time, and the total flow had to be assumed equally divided between the pit and stage uptakes. The flows obtained for both uptakes under similar conditions, however, indicated that they were equal to within 5%. In the trials on *G* furnace, surveys were made in both uptakes during the same reversal interval. The relation between the air flow measured in the uptakes of the two furnaces and the air-meter reading is shown in Fig. 3.

* At the time of these experiments, these furnaces were of the conventional type with two air uptakes at each end. They have now been modified to the single-uptake design.

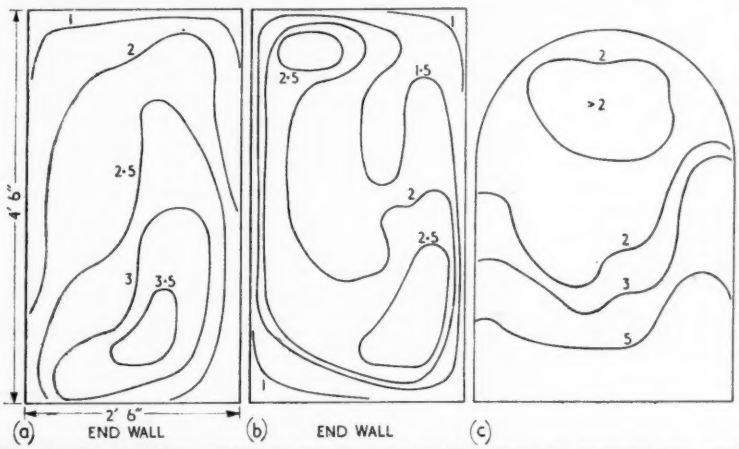

Fig. 4—Typical flow patterns encountered in *R* furnace at Samuel Fox and Co., Ltd. (*a*) in the pit side uptake, (*b*) in the stage side uptake, (*c*) in the culvert. (Figures on contours are velocities in ft./sec. at N.T.P.)

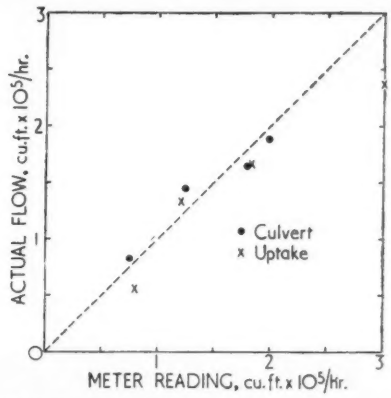

Fig. 5—Relationship between actual and metered air flow in *R* Furnace at Samuel Fox and Co., Ltd.

Work at Stocksbridge

These experiments were carried out on *R* furnace. Temperatures were measured with suction pyrometers which were left *in situ* throughout the trials. Pressure differences were measured with a Kent-type slant gauge, which enabled readings to be obtained more quickly than with the null deflection micromanometer used at Shelton; thus it was possible to measure velocities at 36 points in one reversal period.

Pitot-tube measurements were made in both uptakes simultaneously so as to give the total flow. Similarly, measurements were also made in the culverts below the checkers in order to determine the net loss or gain of air between the base and top of the checkers. Because of the tortuous paths sometimes followed by underground culverts, visualization tests with a lighted gas lance were first carried out to establish the most suitable section for surveying with a Pitot tube. The uptake surveys were carried out about one foot above stage level and the suction pyrometer installed about two feet above stage level.

The flow patterns reconstructed from readings taken in the uptakes and culverts are shown in Fig. 4. The air flows measured

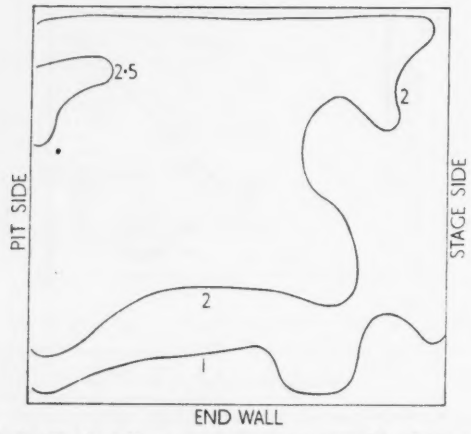

Fig. 6—Typical flow patterns encountered in *A* furnace at Briton Ferry Steel Co., Ltd. (Figures on contours are velocities in ft./sec. at N.T.P.)

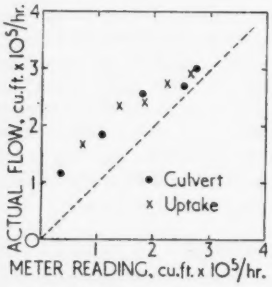

Fig. 7—Relationship between actual and metered air flow in *A* furnace at Briton Ferry Steel Co., Ltd.

in the culvert and uptakes are related to the air-meter readings in Fig. 5. These measurements of flow were carried out as part of a separate investigation to discover what effect coating the checker chambers with a sealing compound had on air infiltration. This work is not yet complete and will be reported separately.

Work at the Briton Ferry Steel Co., Ltd.

These trials were carried out on *A* furnace, which is a single-uptake furnace converted from gas to oil firing. The old gas culvert is now used as an additional air culvert.

Temperatures in the uptake and culverts were measured with suction pyrometers. Pressure differences were measured with a slant gauge, which was more sensitive to small pressure differences than the instrument used during the Stocksbridge work.

For the survey in the uptake, 72 readings were taken at each air flow and flow-pattern diagrams were constructed from these, a typical pattern being shown in Fig. 6. Below the checkers, the Pitot-tube measurements were made in both culverts simultaneously. For each survey, 33 readings were taken in the air culvert and 35 in the old gas culvert. The relationship between the air flow, measured in the uptake and culverts, and the air-meter readings is shown in Fig. 7.

During these trials static pressures were measured at various points in the air circuit to determine whether a positive pressure existed in the flue system between the fan and the furnace chamber. Such a pressure might have resulted in a loss of air through the flue brickwork into the atmosphere. The pressure beyond the fan was less than atmospheric, but this should not be taken as an indication that the fan was not doing useful work. If the fan were removed, the static pressure at this point would probably become even less.

CONCLUSIONS

The main result of these trials has been to show that, where air fans are used, infiltration to the ingoing air system is limited to times when the supply of fan air is restricted. At the high rates of blowing there is a tendency for air to escape between the fan and the furnace port. Most of this presumably escapes across the reversing valve direct to the stack.

Since the normal running range of positive air fans supplying steel melting furnaces is appreciably below their full power, Figs. 3, 5, and 7 suggest that under normal conditions the actual air reaching the furnace port is much nearer to the metered quantity than was hitherto anticipated. Efforts to 'blow hard' lead to considerable leakage of air and hence the air fans now used are apparently more powerful than is necessary; the extra capacity is held in reserve for blowing through blocked checkers or for burning extra fuel.

Acknowledgments

The author wishes to thank the management and staff of the steelworks where the experiments were carried out; Mr. C. Salter of the National Physical Laboratory and Mr. M. P. Newby of the B.I.S.R.A. Physics Department, for advice on the calibration of Pitot tubes; Mr. I. M. D. Halliday of the Research and Development Department, United Steel Companies, who pointed out possible sources of error when using a cold tube in a hot gas; Messrs. M. F. Binney, A. Hague, L. E. Leake, J. G. Lee, E. Rogers, and D. Preston, members of the B.I.S.R.A. Steelmaking Division who took part in the practical work; and also Dr. A. H. Leckie, Head of the Steelmaking Division, for advice and encouragement throughout.

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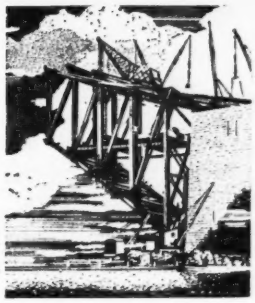
IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE FIFTEENTH MEETING

THE FIFTEENTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP was held at 4 Grosvenor Gardens, London, S.W.1, on Tuesday, 19th June, 1951. Mr. C. H. T. WILLIAMS (Park Gate Iron and Steel Co., Ltd.), Chairman of the Group, occupied the Chair.

THE MORNING SESSION was devoted to the presentation and discussion of the paper: "Protection of Structural Steelwork against Atmospheric Corrosion," by J. C. HUDSON (B.I.S.R.A.) and W. A. JOHNSON (The United Steel Companies, Ltd.).

THE AFTERNOON SESSION was devoted to an open discussion on the Productivity Report: "Materials Handling in Industry" issued by the Anglo-American Council on Productivity after the return from the United States of the responsible Productivity Team. Mr. A. ROEBUCK, leader of the Team, introduced the Report; Mr. J. YOUNG spoke on "Labour Aspects," and Mr. L. W. ROBSON spoke on "Cost Considerations."

PROCEEDINGS OF THE MORNING SESSION: 10.30 A.M. to 12.45 P.M.

Discussion on the Paper—

PROTECTION OF STRUCTURAL STEELWORK AGAINST ATMOSPHERIC CORROSION*

Dr. **J. C. Hudson** (British Iron and Steel Research Association), presented Part I of the paper, and added: It should be emphasized that the 'lives' given in the paper for various painting schemes and protective coatings when applied to steel were obtained under our carefully controlled experimental conditions. They will, therefore, tend to be appreciably greater than those achieved in practice, where disturbing factors, such as mechanical damage, come into play; on the whole, there is not a tremendous disparity between the experimental and practical figures. For example, our results for zinc coatings agree reasonably well with the experience of the Central Electricity Board, who specify that all tower steelwork shall be galvanized with not less than 2 oz./sq. ft. of zinc. In rural districts this coating lasts for 15 or 20 years before it needs painting. In industrial districts the life is from five to ten years, except occasionally where a tower is near some local cause of atmospheric pollution, such as a generating station, when failure may occur in less than five years.

Since the paper was written, the Sub-Committees of the U.S. National Association of Corrosion Engineers, to which I refer on p. 166, has published a report on gritblasting as a surface preparation for painting. Three grades of gritblasting finish are defined, as follows:

Condition No. 1—The white steel surface finish which covers the complete removal of all corrosion products, all millscale, and the grey millscale binder, thus exposing the white metal for a good connection for either the adhesive- or the bonding-type coating. Single nozzle sandblasting will produce from 75 to 140 sq. ft. per nozzle hour ($\frac{5}{16}$-in. nozzle at 100 lb. pressure). It is suggested that nozzle distance from steel surface be 12–18 in.

Condition No. 2—The commercial surface finish which includes the complete removal of all corrosion products, as well as all tight and loose millscale. It does not include the removal of the grey binder. (By 'grey binder,' I presume, is meant the innermost layer of scale which, of course, is of a different consistency from the outer one.) A commercial blasting job will look rather streaky, although it does produce a very excellent surface anchor for coatings either of the adhesive or the bonding type. Preparation speed with sand is 240–450 sq. ft. per nozzle hour ($\frac{5}{16}$-in. nozzle at 100 lb. pressure). It is suggested that nozzle distance from the steel be 18–24 in.

Condition No. 3—The sand brush-off surface finish which includes the complete removal of all corrosion products as well as all of the loose millscale. It does not include the removal of the tight millscale. The sand, however, produces on the tight millscale an anchor pattern, which is found suitable for a coating of either the adhesive or the bonding type. Preparation speed with 30–50 grit sand equals 650–1000 sq. ft. per nozzle hour ($\frac{5}{16}$-in. nozzle at 100 lb.

* *J. Iron Steel Inst.*, 1951, vol. 168, pp. 165–180.

pressure). It is suggested that nozzle distance from the steel surface be 20–30 in. Before applying the coating, the surface should be solvent cleaned.

The main point is that our American friends are endeavouring to use gritblasting economically by varying the operating conditions to suit the particular job.

Since the Protective Coatings (Corrosion) Sub-Committee began their first series of tests ten years' ago, new metallic coatings have become available. The potential difference between the coating metal and the basis steel has an important bearing on the efficiency of the protection achieved. Zinc is anodic to steel, and magnesium still more so; aluminium under practical conditions seems to be less anodic than zinc. For some purposes it is advantageous to have a large potential difference between the coating and the steel but for others a large difference may be wasteful. In our new research, therefore, we are testing coatings of alloys of the metals mentioned, because the potential difference in relation to the steel base will vary over the series and an alloy may prove to have a better combination of properties for use as a coating than the pure metal itself.

We have also undertaken tests on sprayed aluminium coatings of different purities. In industry it is thought that the best results are obtained by using 99·5% pure aluminium but there is little experimental evidence for this view. Aluminium coatings of three different purities, namely, 99·0%, 99·5%, and greater than 99·9%, are, therefore, being exposed to atmospheric corrosion tests.

Mr. **W. A. Johnson** (United Steel Companies, Ltd.) presented Part II of the paper and added: I should like to draw attention to Fig. 7, which is an attempt to convert the superficial area of a section into tonnage, because it is convenient to deal with this matter on an area basis, especially in relation to its economics. A plate half an inch thick (right-hand ordinate) would have a surface area (horizontal scale) of about 200 sq. ft. The illustration is therefore intended to show that for every 1*d*. per sq. ft. which was spent on the plate, the total cost would be about £1 per ton. In this illustration where the words "COST, pounds/ton" occur there should be added "per 1*d*. per sq. ft." I should like to emphasize the importance of the surface condition of the steel before painting. This must be free from rust and scale. The choice of treatment will be governed largely by economic considerations. The initial capital expenditure incurred will probably be justified by the consequent reduction in maintenance costs, which are likely to increase because of increasing labour charges.

(Mr. Johnson concluded his presentation with a number of slides illustrating specially-treated steel structures exposed to industrial atmospheres and now under observation.)

The **Chairman**: As engineers we have not in the past given sufficient thought to the effects of corrosion, but attention is now being given to the matter, and there are relatively long-term investigations by B.I.S.R.A. and other bodies. The application of some of the recommendations, as illustrated today, emphasizes the points made by Dr. Hudson and Mr. Johnson regarding the importance of the subject.

Mr. **V. Watkins** (Steel, Peech and Tozer): It is not possible to over-emphasize the importance of this subject. If some permanent protection of structural steelwork, before it is erected and put into service, could be devised, there would be very substantial savings in costs and trouble to the engineers who are responsible for maintenance.

The works with which I am connected comprise the usual open-hearth melting shops, rolling mills, forges, pickling plant, machine shops, gas producers, etc., all of which are typical of the usual steelworks' layout. They are situated in what is probably the most heavily polluted atmosphere in this country. Success or failure of the structures depends on the initial surface preparation, since maintenance work is carried out only during two weeks in the year, and during this period the cranes are needed for various duties. At no time, therefore, is the shop fully available for painting and cleaning. It is very difficult to clean effectively (and not just give a very superficial brush over with a wire-brush), and to paint buildings in the steel industry under conditions which prevail in the average melting shop. At Steel, Peech and Tozer's we have gone to much trouble and expense, with some success, in an effort to plan this class of work as a routine matter. Even so, we are not yet satisfied that painting and cleaning can be done thoroughly.

In regard to standard galvanized sheeting, of which we have about 52 acres of roof and side sheeting, we have found that, used in the as-received condition, it will give little protection after 12 months. Even if the sheets have a life of ten years we would have to re-sheet about five acres a year. This is economically almost prohibitive and, moreover, we would not be able to get the sheets. We do find that sheeting with an initial protection has a much longer life.

Although it has always been accepted that any steel structural work in a steelworks would corrode, people have not been fully alive to the fact that eventually the structure would completely disintegrate. Recently, when the bases of steel columns in a melting shop were exposed for the first time for very many years, they were found to be almost completely corroded away. Sand- and gritblasting is not impracticable, but it is rather difficult to handle on plants already in operation, without contaminating machine parts.

We have a planned system of inspection of steel structures and roofs which has greatly improved the maintenance of our buildings. Each of our inspectors is given a detailed layout of the parts or items in his area on which he is expected to report.

Mr. **H. Foster** (Park Gate Iron and Steel Co., Ltd.): I agree with Mr. Watkins that it would be an advantage if it were possible to treat the steel in the initial stage before fabrication. The painting of a steelworks' building, which houses a process operating 24 hours a day, causes considerable inconvenience, and is consequently deferred as long as possible. I sometimes wonder whether the danger of non-attention to painting is as high or as important as it is made out to be. At the Park Gate Works we have buildings that have existed from before 1900 and during that period painting has been done about every 15 years, but even neglected parts of the buildings have a surprisingly long life. Slating angles attached to the roof are only $1\frac{3}{4}$ in. × $1\frac{3}{4}$ in. × $\frac{1}{4}$ in.—a form of construction that held good before 1900—and these have not nearly corroded through, and within each of them is embedded a nailing block for slates. I think that the additional initial expense is more than repaid by the saving in subsequent painting costs.

The authors consider red lead to be the most suitable priming paint. I think that provided this priming coat is applied correctly, the nature of the top coat is of minor importance, since it serves only as a sealing coat and enhances the appearance. The recently favoured aluminium finish has a very pleasing appearance, but, unfortunately, in a steelworks the excellent light-reflect-

ing qualities are not lasting, although its protective value lasts considerably longer.

From the paper I should establish red lead as a primer with a sealing coat of one of the bituminous paints as a suitable standard painting scheme for steelworks' structures. A definite set of paint specifications should be put forward by the paint manufacturers.

Mr. **Johnson**: In connection with Mr. Foster's and Mr. Watkins' remarks, a metallic coating, such as aluminium and zinc, deposited on clean steel, is regarded as a primer. The final painting scheme, whilst important, is of secondary consequence. The best and most efficient paint should, however, be applied, since the paint cost is only a fraction of the cost of its application. To apply any paint to badly corroded steel is very largely a waste of money.

A final coating of aluminium paint gives an attractive appearance, but I am not competent to say whether it gives a better final coat than the more conventional paint compositions. Dr. Hudson will probably give an opinion on this.

Dr. Hudson: Our exposure stands are structural steelwork on a small scale and we experience the same difficulties in maintaining them as are encountered in a works. These difficulties are increased by the fact that the repainting of the stands has to be done with all the specimens in position, and the specimens themselves must not be touched. In the early days we relied on painting alone to protect these steel stands, but we now specify that all our stands shall be provided with a metallic coating, either of hot-dipped zinc or of sprayed aluminium. Although this increases the initial cost, maintenance is much cheaper, resulting in a considerable saving.

The channel section in the front of our paint-exposure stands was deliberately left without a metallic coating, so that it could be used for patch-painting tests. Severe corrosion of this member has occurred at Derby within five years and in places on the flanges the rust is $\frac{1}{4}$ in. thick. The observation shows how rapidly corrosion can occur under practical conditions if repainting is not carried out, either because of neglect or because the parts are inaccessible; if there is any doubt about maintenance, the steel should be given a metallic coating, as Mr. Johnson suggests.

Protective measures are not always carried out satisfactorily. I know of some structural members which have been given a single coat of cheap bituminous paint, and there is now little paint left on them and they are rusting badly. In other cases, paint is peeling from galvanized steel roofs because they have been painted without the proper surface preparation needed to ensure paint adhesion to new galvanized steel sheets.

Mr. Watkins' firm are to be congratulated on instituting a regular system of inspection at their works. The German State Railways adopted a similar system before the war and trained men to supervise all the painting and repairs of structures within their organization. Such a policy must pay rich dividends, because if a structure is allowed to rust so badly that surface preparation for repainting cannot be done by the ordinary methods, heavy expense is inevitable if matters are to be put right.

The reasons for the changes in surface colour of aluminium paints are as yet imperfectly understood. They result partly from dust deposition but it is also probable that physical changes take place within the paint film itself. The good reflectivity of an aluminium paint is caused by a thin surface layer of flakes of aluminium floating on top of the paint medium, and if these flakes sink into the paint film, reflectivity will be lost and, if the paint medium is bituminous, the surface will become black. This does not apply to all aluminium paints, because one of the arts of making good aluminium paint is to overcome the tendency for the dry paint film to darken on ageing.

Mr. **Foster**: Many of those present will remember the various works visited during The Iron and Steel Institute Summer Meeting in Zürich in 1947. The machine shops were a splendid example of the correct finish for this type of building, the standard of painting was very high, and the colours selected were most suitable.

Mr. **R. L. Willott** (John Summers and Sons, Ltd.): I agree very largely with what was said by Mr. Foster, but I would like to go a stage further. Structural steelwork, for purposes of this discussion, can perhaps be most conveniently divided into four main categories:

(1) Out-door steelwork subject to fresh all-weather conditions, such as B.E.A. pylons, bridges, pipe gantries, and so on

(2) Steelwork forming part of a steel-framed building, but subject to local atmospheric conditions of a severe nature, *e.g.*, chemical plants, acid works, pickling bays

(3) Steel-framed structures intimately clad with stone, concrete, or brickwork, such as offices, warehouses, and other civil types of construction

(4) Normal steelwork forming a support for overhead crane gantries and a framework for overall corrugated sheet cover.

Pretreatment of steelwork in categories 1 and 2 is of paramount importance and will justify considerable initial expenditure, preferably on the lines indicated by Mr. Johnson. Category 3 steelwork rarely needs elaborate protection, and is usually adequately served by a basic oxide coat during fabrication. Category 4 steelwork forms by far the greatest proportion of superficial area of structural steelwork exposed to atmospheric corrosion. Regardless of its locality in Great Britain, but provided that actual rain is properly denied access (by appropriate renewal of sheeting, attention to gutters, downspouts, etc.), steelwork in this latter category is likely to have a satisfactory structural life without over-elaborate protective treatment by paint or a metallic coating.

Only on aesthetic grounds can I accept the theoretical average life figures which are so frequently quoted for this class of steelwork.

I would support wholeheartedly any thorough initial painting, on the lines recommended by Dr. Hudson, but cannot agree that the expense of gritblasting, metallic spraying, or deposited coatings for structures in category 4 is justified.

Mr. Johnson: I did not intend to give the impression that all new structural steel merits the attention I have suggested, but rather to emphasize the need for the prefabrication treatment of exposed structural steelwork.

The reinforcing bars, which are covered by concrete or reinforced concrete structures, are little affected even after 50 years, if atmospheric effects and the infiltration of water are excluded. On the other hand, special protection is advantageous in gas and chemical plant, where the rate of deterioration of the best paint is very rapid indeed. Some steel structures may, however, require painting at reasonable intervals, for aesthetic reasons, even although they are not exposed to the weather. Good surface preparation and the application of a primer which will remain on the structure throughout its life, may reduce the frequency with which the final painting scheme must be applied.

Dr. **Hudson**: For priming structural steelwork, red lead paint is better than red oxide paint. Our tests

have shown that a priming paint pigmented with a mixture of red lead, white lead, and asbestine gives substantially the same degree of protection as red lead paint and has certain practical advantages as regards brushability and storage.

I agree with Mr. Willott that the standard of protection adopted should be related to the function of the component and one can envisage three or four standards of protection of increasing effectiveness for structural steelwork, corresponding to increasing severity of the conditions to which it is exposed.

In writing our paper, we had in mind steelworks exposed mainly to bad industrial conditions. Inside an open-hearth plant, where the conditions are warm and dry when the furnaces are operating, little maintenance painting of the interior surfaces should prove necessary. There are, however, other industries in which the conditions inside the plants are severely corrosive and where, to ensure successful operation, a high standard of protection for structural steelwork is essential. Tanneries and cotton-spinning mills, for example, have to contend with bad conditions.

Mr. **T. D. Turner** (Igranic Electric Co., Ltd.): We are equipment suppliers, and after listening to the contributors to the discusssion, I have begun to feel that it is probably a complete waste of time painting our equipment when sending it to a steelworks. This cannot be the case, and I feel that the research work that is being done can be of value to the equipment manufacturers and machine-tool supplier.

In view of the fact that there are about 750 paint manufacturers in this country, do the authors think that it will ever be possible for the production engineer, who is not concentrating on the problem of painting heavy steelwork but who has to supply light structural work to steel mills, cement makers, etc., to refer to a paint specification? Will it also be possible for him to buy a corrosion-resistant paint which will give protection for a given period under specified conditions? In certain cases grinding media and vehicles have an effect. I do not know of any paint supplier who publishes formulations against his materials.

Dr. **Hudson**: As I indicated in my opening remarks, there are divergent views about the benefits of compiling hard-and-fast specifications for paints. Personally, as a scientist, I am in favour of giving all the facts to everyone and should welcome such specifications, but I recognize that there is some cogency in the views of the paint manufacturers, who, at the moment, seem reluctant to draw up specifications on a formulation basis. Possibly the problem will ultimately be solved by drawing up performance specifications which would ensure that a paint had certain necessary properties without restricting it to a definite composition. At present, the best practical approach to the problem seems to be to tell the paint manufacturer exactly what is wanted and ask him to supply a suitable paint at a reasonable cost.

The **Chairman**: What is the reference of the document which gives an up-to-date report on the work of your Committee?

Dr. **Hudson**: The reference is to the Second Report of Joint Technical Panel J/P1—Paints for Structural Steelwork—which can be obtained from B.I.S.R.A.

Mr. **J. Bonelle** (Prodorite, Ltd.): I should like to assure Mr. Johnson that the manufacturers are putting in large vats to deal with the dipping process for constructional steel. A plant in Hereford is being extended to deal with very large sections so that the necessity for dipping at both ends will be obviated. In Scotland, after descaling, large ship plates are dipped in a phosphoric acid solution.

I have been going round factories for about 20 years, and I agree that if one paid more attention to the footings, and then took care of the visible corrosion, much damage would be obviated.

Mr. **N. Barron** (Park Gate Iron and Steel Co., Ltd.): The original protection on some of the buildings at Park Gate was probably a very heavy coat of red lead paint, which can still be seen on some structural members. In some places, however, there are no traces of paint and 8 in. × 3 in. steel channels are corroded so that the top flange now consists of $\frac{1}{16}$ in. steel and $1\frac{1}{2}$ in. rust. In a similar building constructed today a competitive design would reduce the section considerably. The original structures have probably stood all this time without further treatment because they were fabricated of heavy sections, the cost of which would be prohibitive today.

The estimated cost of maintenance should have a considerable effect on the design and type of structure chosen for a particular purpose. Mr. Johnson showed a picture of a structure which today might be replaced by a Portal frame; I think I am correct in saying that the surface area of this would be much smaller and cost far less both in initial treatment and subsequent maintenance.

I have found cleaning by chipping effective and much cheaper than flame cleaning and sandblasting, particularly if the paint work on an old structure is in a suitable condition. The brittle paint then comes away with the mill-scale leaving what appears to be a reasonable surface for repainting. I should like to have the authors' comments on this point.

I understand that British Railways now specify the bedding of a layer of felt to the lower portions of some steel bridges, where these are inaccessible for further maintenance. The bridge itself is first treated with an anti-rust primer and then with a coat of bituminous paint and the felt is bedded to this with hot bitumen. This method might be of use in places where particularly heavy corrosion might take place.

Mr. **Johnson**: Mr. Barron has raised some interesting points. Refinement in design and the use of more highly stressed components will not safely permit the heavy deterioration with time to which he refers. Roof-supporting structures with clean and simple outlines of the Portal-frame type have smaller surface areas than the conventional roof trusses, and consequently their initial treatment and maintenance costs would be lower. In regard to chipping, I consider prevention is better than cure.

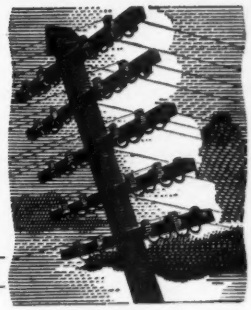
The **Chairman**: In our industry we are now finding many of the ill effects of the long period of war. Many of us are only just beginning to give attention to the buildings and learning how some of them deteriorated during that period.

CORRESPONDENCE

Mr. **E. F. Pellowe** wrote: I do not agree with Dr. Hudson's statement (p. 172) that grease from the galvanizing bath may be one of the main reasons why paints may not adhere well to freshly prepared hot-galvanized surfaces, since grease is rigorously excluded from the galvanizing process. If it is present at any stage, the fluxing mechanism will not operate and an area of steel will remain unprotected. It is true that freshly prepared zinc coatings feel smooth and 'soapy,' but I think this must be attributed entirely to smoothness.

Dr. **Hudson** wrote in reply: I gladly accept Mr. Pellowe's correction.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting

The Annual General Meeting of the Institute will be held in London on **Wednesday and Thursday, 30th April and 1st May, 1952.**

Changes on Council

The following have accepted invitations to serve as Honorary Members of Council :

Professor R. Hay, President of the West of Scotland Iron and Steel Institute

Mr. F. K. Neath, President of the Leeds Metallurgical Society

Mr. L. A. S. Perrett, President of the Swansea and District Metallurgical Society

Mr. V. L. Farthing, President of the Liverpool Metallurgical Society

Mr. N. C. Lake, President of the Cleveland Institution of Engineers

Mr. E. W. Colbeck, President of the Sheffield Metallurgical Association

Dr. G. Baker, President of the Sheffield Society of Engineers and Metallurgists.

Forging and Stamping Bibliography

A bibliography on the Forging and Stamping of Iron and Steel, No. 20 in the Institute's series, has been prepared by the Library and Information Department. The bibliography covers the period between 1920 and 1949, but selected references to literature published before 1920 are included. The bibliography does not include references to the forming of sheet metals.

Bound, duplicated stencilled copies of 184 foolscap pages, may be obtained from the Secretary at 4 Grosvenor Gardens, London, S.W.1, price 25*s*. (15*s*. to Members).

NEWS OF MEMBERS

▶ Mr. K. V. Aiyer has left Aluminium Industries Ltd., Kundara, India, and is now Lecturer at the Indian Institute of Science, Bangalore.

▶ Dr. J. L. Aston, of Coventry, has taken up an appointment in the Science Department of the County Technical College, Wednesbury, Staffs.

▶ Mr. D. L. Atwood has left the Ecko Products Co., Chicago, and has joined Moe Light Inc., Wisconsin, U.S.A.

▶ Mr. M. G. Bader has been awarded the degree of B.Sc. (Metallurgy) of the University of London. He has left the de Havilland Aircraft Co. to complete his National Service in the R.A.F.

▶ Dr. G. Bagna has been appointed Assistant General Manager of the Iron and Steel Division of FIAT S.A., Torino, Italy.

▶ Mr. W. L. Bartlett has been awarded the Ph.D. degree of the University of Wales.

▶ Mr. E. A. G. Croom has been awarded the M.A. and Ph.D. degrees of the University of Cambridge, and has taken up an appointment as metallurgist with the English Electric Co., Ltd., Stafford.

▶ Dr. M. N. Dastur has left The Washburn Wire Co., Phillipsdale, Rhode Island, to take up an appointment with Ramseyer and Miller, Inc. (Consulting Engineers), New York.

▶ Mr. R. P. P. Ellis has resigned from his position with Messrs. Redifon, Ltd., Wandsworth, and has joined The Plessey Co., Ltd., Towcester, as a Development Metallurgist.

▶ Mr. W. W. Franklin, Chief Engineer of Davy and United Engineering Co., Ltd., has been appointed a Director of the Company.

▶ Mr. G. T. Harris, Research Manager of William Jessop and Sons, Ltd., Sheffield, has been appointed Research Director.

▶ Mr. J. B. Haworth, Research Metallurgist with Murex Ltd., Rainham, has been awarded the D.Phil. degree of the University of Oxford.

▶ Mr. R. Haynes, Assistant Lecturer in Metallurgy, University of Leeds, has been awarded the Ph.D. degree of the University of Sheffield.

▶ Mr. S. T. Jazwinski has resigned from the position of Senior Staff Engineer, Metallurgy Department, the Ford Motor Co., Detroit, Michigan. He has been appointed Chief Metallurgist to Central Iron and Steel Co., Harrisburg, Pa., and their subsidiaries, Phœnix Iron and Steel Co. and Chester Iron Co.

▶ Mr. R. T. Keene has taken up an appointment with Messrs. Hoare, Lea, and Partners (Consulting Engineers), Burtonwood, Lancs.

▶ Mr. J. A. N. Lawrie has left the Australian Aluminium Co. and is now employed as metallographer at the Commonwealth Aircraft Corporation Pty., Ltd., Lidcombe, N.S.W., Australia.

▶ Dr. G. D. McAdam has joined the staff of Messrs. Impregnated Diamond Products Ltd., Tuffley Crescent, Glos., as metallurgist.

▶ Mr. H. A. MacColl, Head of the Department of Metallurgy, County Technical College, Wednesbury, has been appointed Principal of the College.

▶ Mr. P. S. McIntosh has left the Research Dept. of Messrs. C. A. Parsons and Co., Ltd., Newcastle-on-Tyne, to take up an appointment as Foundry Technical Assistant with Messrs. K. and L. Steelfounders and Engineers, Ltd., Letchworth, Herts.

▶ Mr. C. E. Mavrocordatos has been appointed Lecturer in Physical Metallurgy at the Birmingham Technical College.

▶ Mr. G. T. Motock, formerly Director of Research, Champion Rivet Co., Cleveland, Ohio, has joined the Union Carbide and Carbon Research Laboratories, Niagara Falls, N.Y., U.S.A.

▶ Mr. B. F. Olds has left Messrs. Hadfields Foundry and Engineering Company to take up an appointment

as Foundry Technical Assistant with Messrs. K. and L. Steelfounders and Engineers, Ltd., Letchworth, Herts.

▶ Dr. W. S. OWEN has been awarded a Commonwealth Fellowship and is carrying out research with Professor Morris Cohen at the Massachusetts Institute of Technology. Dr. Owen has not resigned his appointment at Liverpool University, as stated in the November, 1951, issue of the *Journal*, but is on leave of absence.

▶ Mr. T. PARRY has been appointed a Director of Robin Hood Cycle Co., Ltd., a subsidiary of Raleigh Industries, Ltd., Nottingham.

▶ Mr. R. PRASAD has left Benares Hindu University, and is now a research student in the Department of Metallurgy, University of Cambridge.

▶ Mr. E. G. SPOONER has resigned from the Steel Corporation of Bengal.

▶ Mr. J. G. WALFORD has resigned from the British Iron and Steel Research Association, Sheffield, to take up an appointment as Physicist in the Research and Engineering Department of S. Smith and Sons (England), Ltd., Bishops Cleeve, Nr. Cheltenham.

New Year's Honours

▶ Mr. A. WILLIAMSON, Chairman and Managing Director of William Beardmore and Co., Ltd., Glasgow, has been made a Knight Bachelor.

▶ Mr. G. L. BAILEY, Director of Research, British Non-Ferrous Metals Research Association, has received the C.B.E.

▶ Mr. H. H. BURTON, Director of the English Steel Corporation, Ltd., Sheffield, has received the C.B.E.

▶ Mr. R. T. ROLFE, Chief Metallurgist, W. H. Allen and Sons, has received the O.B.E.

▶ Mr. J. W. R. NADEN, Chief Metallurgist, Chesterfield Tube Co., has received an M.B.E.

Obituary

Mr. ROBERT BURN, formerly of The Precision Engineering Co., Wellington, New Zealand, on 4th December, 1951.

IRON AND STEEL ENGINEERS GROUP

Discussion on Accident Prevention

The Seventeenth Meeting of the Iron and Steel Engineers Group will be held at the Institution of Electrical Engineers, London, on 4th March, 1952, at 10.30 a.m. The Meeting is being organized in co-operation with the Royal Society for the Prevention of Accidents. A buffet luncheon will be served.

In the morning, H.M. Chief Inspector of Factories, Sir George Barnett, K.B., will present a paper on "Accident Prevention in Iron and Steel Works." The afternoon session will be devoted to a paper by Mr. A. Taylor, Chief Safety Engineer of Richard Thomas & Baldwins Ltd., on "Handling of Goods and Lifting Machinery."

The Papers will be presented in full at the Meeting and a précis will be distributed beforehand to all those taking part in the Meeting.

Eighteenth Meeting

The Eighteenth Meeting of the Iron and Steel Engineers Group will be held at 4 Grosvenor Gardens, London, S.W.1., on Thursday, 17th April, 1952, at 10.30 a.m.

The Morning Session will be devoted to a discussion on the paper "Supply and Use of Hydraulic Power at Appleby-Frodingham" by L. N. Lloyd (March 1952), and the Afternoon Session to a paper "Pump Designs and Applications in Iron and Steel Works," by C. G. Evans (April 1952).

A buffet luncheon will be served in the Library of the Institute.

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Staffordshire Iron and Steel Institute

Annual Dinner

Lord Lindsay of Birker will be the principal guest at the Annual Dinner of the Staffordshire Iron and Steel Institute to be held on Thursday, 21st February, 1952.

Associate Section

The Associate Section of the Staffordshire Iron and Steel Institute has now been re-established.

INSTITUTION OF METALLURGISTS

Examination Results

The following result was inadvertently omitted from the list of successful candidates, published in the December, 1951, issue of the *Journal*.

Fellowship—G. R. Morton (Coventry)

NEWS OF SCIENCE AND INDUSTRY

Symposium on Lubrication of Gears

A Symposium on the Lubrication of Gears and the Testing of Gear Lubricants will be held at the Institute of Petroleum, Manson House, 26 Portland Place, London, W.1., on Wednesday, 13th February, 1952.

The first session, commencing at 2.30 p.m., will deal with the lubrication of gears and will include papers on the hydrodynamic theory of gear lubrication, gear tooth wear, gear scuffing, the effect of variation in viscosity with pressure on the load-carrying capacity of the oil film between gear teeth, and the wear and pitting of bronze discs operated under simulated worm-gear conditions. The second session, which commences at 5.30 p.m., will be on the testing of gear lubricants. The papers will cover the development of a test method for gear lubricants, the application of laboratory results to service performance, the production of lubricant test gears, their testing and performance for high-speed gears, the testing of hypoid axle lubricants, and service tests in rear axles of buses and trolley-buses.

Symposium on the Physical Chemistry of Molten Oxides, Sulphides, Silicates, and other Salts

A Symposium on the physical chemistry of molten oxides, sulphides, silicates, and other salts will be held on Wednesday, 20th February, 1952, by the Nuffield Research Group in Extraction Metallurgy, at the Royal School of Mines, London. Particular attention will be paid to slags and matters of importance in metal extraction. Further details can be obtained on application to Dr. F. D. Richardson, Imperial College of Science and Technology, Royal School of Mines, London, S.W.7.

Plastic Deformation of Metals

The Postgraduate School in Physical Metallurgy, University of Sheffield, will hold a special course on plastic deformation of metals from 31st March to 4th April, 1952. The course is intended primarily for industrial scientists and will include both lectures and practical work. The more fundamental aspects of the deformation of metals will be surveyed and where possible the results will be related to practice.

International Congress on Analytical Chemistry

An International Congress on Analytical Chemistry will be held at the Examination Schools, Oxford, from 4th–9th September, 1952. Three main Congress Lectures by eminent chemists have been arranged. Preprints of papers to be presented at the Congress will be available before the meeting and the whole proceedings will be published in a special number, or numbers, of the *Analyst*. Working demonstrations illustrating new techniques or special applications of older techniques in analytical chemistry will be exhibited. Visits have been planned and, at the weekend, a number of excursions to places of interest will be arranged.

Further particulars may be obtained from the Honorary Secretary of the Congress, Mr. R. C. Chirnside, Research Laboratories, The General Electric Co., Ltd., Wembley, Middlesex.

4th Liège International Fair

The 4th Liège International Fair will be held from 26th April to 11th May, 1952. Details may be obtained from Monsieur Paul Lejeune, Foire Internationale de Liège, 17 boulevard d'Avroy, Liège, Belgium.

Sheet and Strip Metal Users' Technical Association

A Midlands Branch of the Association has now been formed under the Chairmanship of Mr. M. E. Guermont (Fisher and Ludlow Ltd.). The Hon. Secretary is Mr. E. N. Salmon (Austin Motor Co., Ltd.).

The first meeting of the Branch will be held at the Chamber of Commerce, New Street, Birmingham, on 13th February, 1952.

Fuel Research 1946–49

The transition from short-term wartime researches to post-war reconstruction projects is described in "Fuel Research 1946 to 1949." The report describes experiments on the gasification of fine low-grade coals and cokes, using the 'fluidized-solids' technique, to provide producer gas, water gas, and gas for the synthesis of oils. If producer gas made in this way were used for heating retorts in gasworks, additional large coke could be made available for other purposes. Although coal cannot directly replace oil as a fuel for many purposes, some of the advantages of oil can be achieved by burning coal in a pulverized form. Special burners for pulverized fuel, designed at the Fuel Research Station, are widely used in industry, and the station is now engaged on the design and development of combustion chambers to enable coal to be used to provide the energy for gas turbines.

With the ending of the war increased attention has been given to atmospheric pollution, and the number of local authorities co-operating by maintaining measuring instruments has greatly increased. Special investigations of the pollution of the atmosphere by oxides of sulphur have been made.

Many other activities of the Fuel Research Board are also described in the report.

Chemical Research Laboratory

Fundamental research carried out to correlate the results of oxidation studies on evaporated metal films under rigorous conditions with similar experiments on massive metal surfaces, are included in "Chemistry Research, 1950," published by H.M.S.O. An account of the work of the Pure Metals Committee indicates that the stock of metals now comprises antimony, cobalt, iridium, iron, lithium, potassium, silicon, and vanadium, in a satisfactory state of purity.

British Tar Federation

Sir Walter Benton Jones, Bt. has been elected President of the British Tar Confederation for the year 1951/52.

Changes of Address

THE BRITISH ALUMINIUM CO., LTD. have now returned to their former offices at Norfolk House, St. James's

Square, London, S.W.1. (Tel. No.: WHItehall 7868).

TUFNOL LTD. The new address of the Midland Area Sales Office of Tufnol Ltd. is Cornwall Buildings, 45 Newhall Street, Birmingham 3.

DIARY

4th Feb.—CLEVELAND INSTITUTION OF ENGINEERS—"*The Development of the Wilton Site*," by R. E. Newell—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 P.M.

5th Feb.—INSTITUTE OF METALS (Sheffield Local Section)—Joint Meeting with Sheffield Metallurgical Association—"*Coating of Billets with Special Reference to Continuous Casting*," by E. Scheuer—Grand Hotel, Sheffield, 7 P.M.

6th Feb.—MANCHESTER METALLURGICAL SOCIETY (Joint Meeting with The Iron and Steel Institute)—"*The Continuous Casting of Steel*," by J. Savage—The Engineers' Club, Albert Square, Manchester, 6.30 P.M.

7th Feb.—LEEDS METALLURGICAL SOCIETY—"*The Low-Temperature Properties of Metals*," by D. W. Naylor—Chemistry Department, The University, Leeds, 7 P.M.

7th Feb.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—"*Tube Production*," by J. S. Blair—Station Hotel, Dudley, 7.30 P.M.

7th Feb.—INSTITUTE OF METALS (London Local Section)—"*Chromium and Chromium-Rich Alloys*," by A. H. Sully—4 Grosvenor Gardens, London, S.W.1, 7 P.M.

8th Feb.—LIVERPOOL METALLURGICAL SOCIETY (Joint Meeting with Society of Chemical Industry)—"*Some Technical and Economic Problems in the Conservation of Fuel*," by A. L. ROBERTS—Old Chemical Lecture Theatre, The University, Brownlow Street, Liverpool, 7.0 P.M.

12th Feb.—SHEFFIELD METALLURGICAL ASSOCIATION (Joint Meeting with Royal Institute of Chemistry)—"*Physical Chemistry in Steelmaking*," by Sir C. Goodeve—Grand Hotel, Sheffield, 7 P.M.

13th Feb.—NORTH WALES METALLURGICAL SOCIETY—"*Recent Developments in Cast Rolls*," by K. H. Wright—County Primary School, Plymouth Street, Shotton, Nr. Chester, 7.15 P.M.

16th Feb.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Joint Meeting with The Iron and Steel Institute—"*The Use of Oxygen in British Electric Furnace Practice—Pt. I*," by T. H. Harris and D. J. O. Brandt—Central Library, Swansea, 6.30 P.M.

18th Feb.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—"*The Work of the Metal-Working Laboratories of the British Iron and Steel Research Association*," by W. C. F. Hessenberg—The University Building, St. George's Square, Sheffield, 7.30 P.M.

19th Feb.—LINCOLNSHIRE IRON AND STEEL INSTITUTE—"*Engineering Maintenance*," by K. Paterson, G. C. Oram, and P. Dixon—Wortley Hotel, Scunthorpe, 7.30 P.M.

19th Feb.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Modern Steel Plant Construction*," by J. W. Holden—Grand Hotel, Sheffield, 7 P.M.

20th Feb.—MANCHESTER METALLURGICAL SOCIETY—"*Extrusion*," by J. CROWTHER—The Engineers' Club, Albert Square, Manchester, 6.30 P.M.

20th Feb.—NUFFIELD RESEARCH GROUP IN EXTRACTION METALLURGY—Symposium on Physical Chemistry of Molten Oxides, Sulphides, Silicates, and other Salts—Imperial College, Royal School of Mines, London, S.W.7.

20th Feb.—SOCIETY OF INSTRUMENT TECHNOLOGY—"*Fundamentals of Flow Measurement with particular reference to Orifice Meters*," by W. J. Clark—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.30 P.M.

21st Feb.—INSTITUTION OF PRODUCTION ENGINEERS (Glasgow Section)—"*Engineering in the Foundry*," by J. Arnott—39 Elmbank Crescent, Glasgow, C.2, 7.30 P.M.

22nd Feb.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Metallurgical Application of Radioactive Tracers*," by H. M. Finniston—39 Elmbank Crescent, Glasgow, C.2, 6.45 P.M.

26th Feb.—INSTITUTION OF PRODUCTION ENGINEERS (Luton Section)—"*Drop Forging*," by J. C. Sharman—Small Assembly Room, Town Hall, Luton, 7.15 P.M.

26th Feb.—SHEFFIELD METALLURGICAL ASSOCIATION—"*X-ray Crystallography Applied to Analytical Problems*," by K. W. Andrews—Grand Hotel, Sheffield, 7 P.M.

27th Feb.—INSTITUTION OF PRODUCTION ENGINEERS (Shrewsbury Sub-Section)—"*Pattern for Progress—Production of Steel, Sheet, and Tin Plate*," by A. S. Huxley—The Walker Technical College, Oakengates, Salop, 7.30 P.M.

28th Feb.—INSTITUTE OF METALS (Birmingham Local Section)—"*Metallurgical Research in the U.S.A.*," by C. S. Barnett—James Watt Memorial Institute, Great Charles Street, Birmingham, 7 P.M.

29th Feb.—INSTITUTE OF METALS (Birmingham Local Section)—All-day Symposium on "*New Techniques of Metallurgical Research*"—Opening Address by A. G. QUARRELL—Birmingham College of Technology, 10.30 A.M.

TRANSLATION SERVICE

(The previous announcement was made in the January, 1952, issue of the *Journal*, p. 58.)

TRANSLATIONS AVAILABLE

No. 431 (German). H. DIERGARTEN: "The Grading of Ball Race Steels by the Inclusion Count." (*Archiv für das Eisenhüttenwesen*, 1936, vol. 10, Nov., pp. 197–204; discussion, pp. 204–210). (Translation made available through the courtesy of Mr. G. W. Giles, of Messrs. Thos. Firth and John Brown, Ltd., and The British Iron and Steel Research Association. Members of that Association may obtain copies free of charge on application to B.I.S.R.A.).

No. 432 (German). E. PIWOWARSKY: "Status, Development and Future of Nodular Grey Cast Iron." (*Neue Giesserei*, Technisch-Wissenschaftliche Biehefte, 1950, No. 4, Dec., pp. 175–180).

TRANSLATIONS IN COURSE OF PREPARATION

(Spanish). E. DIAZ-VARELA CEANO-VIVAS: "Magnetic Sheets." (Instituto del Hierro y del Acero, 1950, vol. 3, Apr./June, pp. 115–131).

(German). A. STAERKER: "New Knowledge in the Field of the Surface Protection of Refractory Bricks." (*Tonindustrie-Zeitung*, 1951, vol. 75, No. 3/4, pp. 33–36).

(German). E. SIEBEL and S. SCHWAIGERER: "The Strength of Tubes under Internal Pressure at very High Temperatures." (*Brennstoff, Warme, Kraft*, 1951, vol. 3, May, pp. 141–143).

(Polish). K. RADZWICKI and J. KOZIELSKI: "Diffusion Deoxidation with Coke in the Basic Open-Hearth Furnace." (*Prace Glównego Instituto Metalurgii*, 1951, No. 4, pp. 267–277).

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The Wealth of Former Metal Mines in the Vosges. V. Charrin. (*Génie Civil*, 1950, **127**, July 15, 270–272). The nature and history of these mines are reviewed, with reference to their possible re-exploitation. Particular attention is given to Ste.-Marie-aux-Mines, Lacroix-aux-Mines, Giromagny, Auxelles, and Plancher-aux-Mines.—T. E. D.

The Geology of the Iron Ore Deposits in the Chalk-Basin near Damme. H. Willert. (*Glückauf*, 1951, **87**, July, 643–647). The geological features of iron-ore deposits containing about 20% of iron, situated in the North German province of Oldenburg, are described.—P. F.

Metallurgical Coals of the Crowsnest Area. E. J. Burrough. (*Canad. Min. Met. Bull.*, 1951, **44**, June, 412–414). Recent estimates put Canadian bituminous coal reserves at 8×10^9 tons, of which $4{\cdot}7 \times 10^9$ tons are located in the Crowsnest Pass fields. The latter contain little sulphur, but variable ash (6–20%); the marked friability is useful in coking. A blocky coke of fine cell structure is produced. Coke standards and markets are surveyed and coke-oven practice is discussed together with production costs.—T. E. D.

Labrador's Iron Age. F. Illingworth. (*Mine Quarry Eng.*, 1951, **17**, June, 185–188). The Labrador iron formation is part of a highly thrust-faulted sedimentary series with high dips and folds. Survey indicates that the deposits exceed 400 million tons of surface ore with a definite manganese ore body. The ore is chiefly hematite with some bands of limonite. Samples average 58½% iron although the content has occasionally been as high as 65%. The opening-up of these deposits will probably be completed by 1954–55.—E. C.

Potential Sources of Iron Ore Bolster Conservation Program. O. R. Rice. (*Steel*, 1951, **129**, Oct. 1, 88–91). The author discusses the position with respect to high-grade American lake ores and suggests that there are sufficient workable quantities of these ores to last about 25 years. The large iron-ore reserves of Venezuela and Labrador are considered together with the large deposits of iron-bearing taconites which contain between 25% and 35% iron. Reference is made to the commercially feasible means of concentrating the magnetic taconites to a 63% iron product—M. D. J. B.

The Geology and Mineral Resources of Sierra Leone. J. D. Pollett. (*Colonial Geology and Mineral Resources*, 1951, **2**, No. 1, 3–28, H.M. Stationery Office). There are several large deposits of iron ore but only the hematite deposits have been mined. Much of the ore is of acid Bessemer grade.—R. A. R.

ORES—MINING AND TREATMENT

Tungsten Carbide Tipped Rock Drill Bits. J. C. Heaslip. (*Canad. Min. Met. Bull.*, 1951, **44**, June, 419–423). The advent of the detachable drill bit resulted in a great improvement in rock drills. Tungsten carbide bits enable as much as 400 ft. of rock to be drilled without change, and also require lighter equipment. 'Carset Jack-bits' before and after service are illustrated.—T. E. D.

Iron Ore Now Being Shipped from Bethlehem Steel Company's Mine in Venezuela. (*Blast Furn. Steel Plant*, 1951, **39**, June, 679–683, 687). Open-cast mining is used and high-grade hematite ore is obtained. The loading and crushing equipment at the river port of Palua is described. Details are given of the pier structure and ramp at the river-craft terminus of Puerto de Hierro. Electric power is generated at 2400 V. and 60 cycles in three separate power stations for the plants at Palua, Puerto de Hierro, and the mine at El Pao.—J. P. S.

Conveyor Belt Stackers Facilitate Iron Ore Handling. (*Steel*, 1951, **129**, July 9, 96). This article describes two different types of conveyor stacker installed at a mine of the Cleveland-Cliffs Iron Co. The first stacker consists of a 30-in. troughed belt conveyor mounted on a 60-ft. steel boom, supported in a fixed inclined position. The belt operates at 440 ft./min. and can stack ore at 300 tons/hr. The second stacker is a versatile, self-propelled type, travelling on a wide-gauge track; it has a 100-ft. radius boom carrying a 24-in. belt.—M. D. J. B.

Investigations into Increasing the Efficiency of Band Sintering Plants. H. Pohl. (*Iron Steel Inst., Translation Series*, 1951, No. 426). This is an English translation of a paper which appeared in *Stahl u. Eisen*, 1951, **71**, June 7, 597–605; June 21, 664–669 (*see J. Iron Steel Inst.*, 1951, **169**, Dec., 394).

On the Preparation of Siegerland Iron-Bearing Slimes. G. Gerth. (*Z. Erz. u. Met.*, 1951, **4**, Sept., 334–337). Two methods used for the enrichment of iron-bearing slimes are described, one involving the use of a centrifuge, the other a hearth of the Linkenbach type. The latter method closely resembles that used in the preparation of kaolin. Data concerning efficiency of extraction are given.—P. F.

Design and Operation of National Tube's Sintering Plant. E. O. Austermiller and W. A. Cureton. (*Iron Steel Eng.*, 1951, **28**, Oct., 111–117). This article describes the new sintering plant of the National Tube Co. completed in 1949.

Plant layout, the raw materials problem and the flow of materials from start to finish of the process are discussed in detail. The sinter belt is 6 ft. wide and 51 ft. long. The rated capacity is 500 tons/day. The 77 pallets of the machine pass over eight wind boxes at a speed of 40 to 96 in./min.

Progress Revealed in Pelletizing Magnetic Taconite Concentrate. E. W. Davis and H. H. Wade. (*Steel*, 1951, **129**, June 30, 82–90). Developments in pelletizing are reported. Balling procedure is described in detail together with tests carried out to compare balling characteristics of various ores. A description is given of a simple brick-lined cylindrical-shafted furnace 7 ft. high and 3 ft. in dia. for pelletizing. Operational details are given.—M. D. J. B.

FUEL—PREPARATION, PROPERTIES, AND USES

Enlarging Steam Plant at Irvin Works. R. Lacy. (*Iron Steel Eng.*, 1951, **28**, Oct., 129–131). The author describes the boiler-plant enlargements at the Irvin Works of The United States Steel Company. The works, with an original rated capacity of 600,000 tons per annum, today under normal operating conditions achieves 2,000,000 tons a year. The steam generating equipment and power-house anxiliaries are described.—M. D. J. B.

Instrumentation and Control for Small Power Plants. P. S. Dickey. (Midwest Power Conf., *Blast Furn. Steel Plant*, 1951, **39**, June, 694–696, 698–699, 704). The types of plant considered are small coal-fired boilers, small oil- or gas-fired boilers, medium-sized boilers for industry, and control station power plants. The objectives for instrumentation and control are improvement of fuel economy, minimizing of overall cost, safe and reliable operation, and the efficient utilization of operating personnel. The author states that there is now ample operating experience available to indicate the desirability of combining boiler, turbine, and possibly electrical controls for one or more units in one centralized supervisory station.—J. P. S.

Oven Flame Failure Devices. (Indust. Gas Dev. Committee Report, 50/3/58 D 036: *Indust. Finishing*, 1951, **3**, June, 868–874; July, 983–992). Every flame-failure device must prevent gas from being supplied to the main burner until the pilot flame is established; after flame failure the device must completely stop all gas flow to the appliances. The device should tolerate reasonable fluctuation in gas pressure and combustion characteristics and reasonable variations in ambient temperature and air speed. The types of device at present used are discussed. In Part II the general requirements which have to be observed in the installation of flame-failure devices are dealt with.—E. T. T.

Recuperation of Heat in Metallurgical Furnaces. J. E. Lafon. (*Mét. Constr. Mécan.*, 1951, **83**, July, 539–541; Aug., 595–597). The general technical aspects of recuperation, the evaluation of the gains thus made and the main types of recuperator (including metallic) are described.—R. S.

The Sampling of Small Coal. E. T. G. Emery. (*Engineering*, 1951, **172**, Oct. 12, 452–454). The author deals with the theory of coal sampling as normally carried out and expresses the practical rules in terms of functions ordinarily used in statistical work.—M. D. J. B.

Demand for High-Quality Coal Taxes Mechanical Cleaning Units. J. Griffen. (*Steel*, 1951, **129**, July 2, 84–101). Methods for improving coal quality are considered. These include mechanical cleaning, which is economical and produces a coal acceptable to most markets, and heavy-media processes. The Tromp heavy-medium process developed in Holland, is described in detail. A French cleaning installation is also described and tests carried out by the French Coal Administration depicting sharpness of separation are discussed. Froth flotation as practised in England is also examined.—M. D. J. B.

Progress in Coal Preparation during 60 Years. W. R. Chapman and L. W. Needham. (Nat. Assoc. Colliery Man., *Iron Coal Trades Rev.*, 1951, **163**, Oct. 12, 795–800; Oct. 19, 857–863). In this review the authors first discuss the changes in the nature of coal and in mining methods and market requirements. The available coal-cleaning processes and developments in plant design are then reviewed, and progress in the study of the fundamental principles, performance, and efficiency is considered. The importance of coal preparation in relation to the industry in general is discussed.—G. F.

Survey of Coke Making in the Saar. M. Bouillot. (*Rev. Ind. Min.*, 1951, **32**, Sept., 267–276). Saar coke which is fluffy, weak, and needle-like has to be adapted to suit the requirements of Lorraine blast-furnaces. Trials are described and it is hoped shortly to make suitable coke by blending bituminous coal with coke breeze and semi-coke, perhaps using selective grinding.—A. G.

Coke-Oven Plant at Margam Works: The New Units in Operation. (*Iron Coal Trades Rev.*, 1951, **163**, Oct. 12, 809–813). Descriptions are given of the new coke-oven units and auxiliary plant now in operation at Margam Works of The Steel Company of Wales Ltd. These consist of additional coke ovens with a new washery and coal-preparation plant to deal with the entire coal supply, and a new coke-screening and by-product plant to deal with all coke and gas from both the new and existing coke ovens. The plant is well instrumented.—G. F.

Coking Practice at the Tata Iron and Steel Works, Jamshedpur. S. N. Sircar. (*Tisco Rev.*, 1951, **19**, Apr., 385–392). This is a survey of the origin and development of the coking unit of the Tata Iron and Steel Co. The operation of Evance Coppee non-recovery ovens, Kopper's ovens, Wilputte ovens, slot bunkers, and Simon Carves ovens is discussed.—E. T. T.

Cyanides from the Coke Oven. M. L. Kastens and R. Barraclough. (*Indust. and Eng. Chem.*, 1951, **43**, Sept., 1882–1892). A complete and detailed description is given of Kopper's Co. Inc. plant at Kearney N.J., for the recovery and production of hydrogen cyanide and cyanides from coke-oven gases. Hydrogen sulphide is also recovered, and used in the manufacture of sulphuric acid.—C. J. B. F.

Means of Achieving Optimum Yields of Carbon By-Products in Coking Plants, with Special Reference to the Temperature-Control System. F. Trefny. (*Glückauf*, 1951, **87**, June, 537–551). Optimum extraction of aromatic by-products in coking plants depends mainly upon efficient temperature control. Temperature-controlling systems in use are discussed and their operation examined. The introduction of an automatic control system, adjustable to the peculiarities of design of the plant and to the nature of the charge is recommended. A control system suitable for this purpose is described, and the economic aspects of installing and using it are analysed.—P. F.

Cleaning Combustion Gases—Present State of Development. M. Andritzky. (*IVA*, 1949, **20**, No. 6, 274–287). [In German]. Some centrifugal dust collectors and one electrostatic precipitator are evaluated and compared.—R. A. R.

Venturi Scrubbers—Efficient, Low Cost Gas Cleaners. W. P. Jones. (*Steel*, 1951, **129**, June 30, 70–72). A description is given of the venturi scrubber for controlling air pollution by removal of solids down to micron size from effluent gases. The advantages of this scrubber are proved efficiency, moderate overall cost, and simplicity of operation and maintenance. It is claimed that it is a superior primary washer at moderate pressure drops where secondary cleaning follows, and may combine the functions of a primary washer and a fine gas cleaner when operated at the higher pressure drops.—M. D. J. B.

The "Deoxo" Method of Gas Purification. (*Engineering*, 1951, **172**, Oct. 5, 428). A description is given of a simple method of removing the small quantities of oxygen or hydrogen which usually contaminate commercial gases. The equipment, developed in the U.S.A. by Baker and Co. Inc., is now made available in Britain by Baker Platinum, Ltd., London. The process depends upon the combination of oxygen and hydrogen in the presence of a catalyst, the catalyst being one of the platinum group of metals deposited on a suitable support.—M. D. J. B.

TEMPERATURE MEASUREMENT AND CONTROL

Immersion Pyrometry in Steelworks: Recent Developments and Need for Higher Temperature Measurement. (*Iron Coal Trades Rev.*, 1951, **163**, Oct. 12, 803–808). A summary is presented of the proceedings of the second session of the B.I.S.R.A. Steelmaking Conference held in September, 1951, on liquid steel temperature measurement. Papers were presented on quick and period immersion pyrometry, and on the measurement of temperatures above 1700° C. by means of thermocouples of new platinum–rhodium alloys and of tungsten–molybdenum.—G. F.

Temperature Measurement in Flame Hardening. H. Heitmüller and H. W. Grönegress. (*Werkstatt u. Betrieb*, 1950, **83**, July, 322–324). The 'Milliskop' is an optical pyrometer designed to measure the rapidly increasing temperature in flame-hardening. Light from the work piece and a lamp falls alternately on a photocell, the lamp current, which gives a zero A.C. output, being a measure of the temperature. The range is from 200 to 1500° C. with an accuracy of ± 10° C. at 1000° C.—H. R. M.

The Measurement of High Temperatures. P. Rodicq. (*Fonderie*, 1951, **64**, Apr., 2423–2438). The immersion pyrometer is described and the measurement of liquid steel temperatures by the Leeds and Northrup Rayotube method is reviewed. Finally, immersion pyrometer methods are compared with optical methods.—R. S.

Measurement of High Temperatures in Gas Flows. G. Dätwyler. (*Compt. Rend.*, 1951, **233**, July 9, 131–133). A hot-wire anemometer serves both as an anemometer and resistance thermometer. When the temperature of the wire equals that of the gas the value of the current due to thermal turbulence has a pronounced minimum, and variation in speed of gas flow has no effect. The resistance of the wire is then measured to determine the gas temperature.—A. G.

High Speed Reheating of Seamless Steel Tubes. H. W. Cox. (*Indust. Heating*, 1951, **18**, May, 837–844). The use of radiation pyrometry for control of a new high-gradient heating process and the basic principles of this type of heating and the furnace installation itself are described.—J.A.L.

The Electroflo Electronic Potentiometer.—Electroflo Meters Co., Ltd. (*J. B'ham Met. Soc.*, 1950, **30**, Dec., 130–134). The Electroflo electronic potentiometer and its application to industrial control systems are described.—J. B. B.

New Elliott Developments in Temperature Measurement and Control. Elliott Brothers (London) Ltd. (*J. B'ham Met. Soc.*, 1950, **30**, Dec., 135–137). The Elliott Magnetic Amplifier, whereby thermocouple e.m.f.'s can be used to operate control systems, and the Elliott radiation pyrometer, amplifier, and recorder are described.—J. B. B.

Recent Developments in Temperature Measurement and Control. H. A. Stevenson. (*J. B'ham Met. Soc.*, 1950, **30**, Dec., 138–143). An improved moving-coil galvanometer and potentiometer, both developed by Ether Ltd., is used in conjunction with an electronic circuit developed by the Wheelco Instrument Co. to form accurate temperature controllers. The Ether 'Forgemaster' radiation pyrometer can be used to record or control temperatures in the 700–3000° C. range.—J. B. B.

Teloscale Large Scale Illuminated Indicator for Foundry Use. Foster Instrument Co., Ltd. (*J. B'ham Met. Soc.*, 1950, **30**, Dec., 144–151). The Teloscale Indicator of the Foster Instrument Co., Ltd., has been developed for use in foundries. A thermocouple e.m.f. is fed to a moving-coil galvanometer, and the scale image is optically projected to a translucent screen. The visible portion is 11 in. wide, corresponding to a range of 200° C.; it can be read at some distance. The Foster disappearing-filament pyrometer and electronic indicating controller are also described.—J. B. B.

Temperature Control of Slot or Batch Type Steel Forging Furnaces. J. A. Hartnell. (*J. B'ham Met. Soc.*, 1950, **30**, Dec., 152–155). The Honeywell-Brown Radiamatic radiation detector is coupled to a Honeywell-Brown Electronik potentiometer controller to give a robust and accurate system for the temperature control of steel forging furnaces.—J. B. B.

A New Surface Pyrometer. M. D. Drury and T. Land. (*J. B'ham Met. Soc.*, 1950, **30**, Dec., 156–159). A hemispherical reflector is placed on the surface of the hot body whose temperature it is desired to measure. Black-body radiation escapes from a small hole in the top of the hemisphere and the reading of a galvanometer connected to a thermopile above this hole is independent of the emissivity of the surface. The instrument measures surface temperatures in the 300–900° C. range within 10° C.—J. B. B.

Some Equipment Used for the Automatic Control of Temperatures. H. Williamson. (*J. B'ham Met. Soc.*, 1950, **30**, Dec., 160–167). Recent developments in the field of the automatic control of temperatures are briefly reviewed under the following headings: Proportional controllers, narrow and wide proportional band controllers, two-term controllers (proportional plus integral), and three-term controllers (proportional plus integral plus derivative). Furnace-pressure control and valve positioners are briefly discussed.—J. B. B.

REFRACTORY MATERIALS

Recent Technical Progress in Basic Steel Furnace Refractories. F. I. Cordwell. (*Refract. J.*, 1951, **27**, Apr., 128–137; Aug., 319–329). All-basic open-hearth-furnace operating data given by P. Bremer (*see J. Iron Steel Inst.*, 1951, **169**, Sept., 53), are quoted in order to facilitate a fair comparison of acid and basic roof life and cost. It appeared that the total costs for a chrome-magnesite 40-ton furnace compared with those for silica construction stood in the ratio of 1 : 0·92. It was generally assumed that chrome-magnesite crowns last three times as long as silica. The useful data in the text and discussion include a diagram relating the consumption of Radex E bricks to charge weight.—E. J. D. S.

Contribution to the Study of Sillimanite and Mullite by X-Rays. W. L. de Keyser. (*Trans. Brit. Cer. Soc.*, 1951, **50**, Sept., 349–364). A method is proposed for distinguishing sillimanite from mullite by means of X-rays and the Geiger counter spectrometer. Various methods of synthesizing mullite and of mullitizing alumino-silicate products are described.

The Destruction of Refractories. (*Tecn. Indust.*, 1951, **29**, Sept., 895–896). [In Spanish]. Factors affecting the deformation and disintegration of refractories are discussed.—R. S.

Steel Ladle Refractories—Part III. F. I. Cordwell. (*Refract. J.*, 1951, **27**, Jan., 4–10). The production and performance of carbon-impregnated nozzle and stopper refractories are discussed. About 1·5 to 2·0% of carbon in a fireclay body improves the thermal load test properties, but little improvement in slag resistance has been observed. However, carbon-containing stoppers and nozzles are less prone to sticking during teeming.—E. J. D. S.

Refractories from the Users' Point of View. W. L. Kerlie. (*Refract. J.*, 1951, **27**, Mar., 84–95). The selection and performance of refractories under service conditions as applied to blast-furnace and steelplant operation are discussed. Data are presented to show the general trends in open-hearth refractories consumption (including fettling materials) when related to steelmaking conditions such as tapping carbon content, refining time, and slag basicity. The function of oxygen and FeO in the mechanism of erosion of refractories is examined. Mixers, coke ovens, converters, casting-pit refractories, and reheating furnaces are dealt with.—E. J. D. S.

Open-Hearth and Electric Furnace Refractories. J. R. Cady. (*Amer. Inst. Min. Met. Eng.: Blast Furn. Steel Plant*, 1951, **39**, June, 684–687). The selection of refractories is discussed and the properties of silica and basic bricks are reviewed.—J. P. S.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Radio Active Tracers Aid Blast Furnace Research. E. W. Voice. (*Steel*, 1951, **129**, Sept. 10, 102–107). The author describes radioactive tracer technique used recently in Great Britain to develop new means for measuring the time of gas transit through the blast-furnace and the rate of refractory wear in the lining. Radon is used, being the most easily available inert radioactive gas. Experiments at several English works are described.—M. D. J. B.

Effects of Manganese and Its Oxide on Desulphurization by Blast-Furnace Type Slags. N. J. Grant, U. Kalling, and J. Chipman. (*Amer. Inst. Min. Met. Eng.*, 1951, Aug., 666–671; *J. Met.*, 1951, **3**, Aug.). The experiments described were made chiefly to determine the effect of additions of manganese and MnO to blast-furnace slags on the desulphurization of iron, the metal–slag mixtures being stirred in a graphite crucible in an atmosphere of CO. The results show that MnO is readily reduced and causes an almost immediate reversion of sulphur into the metal. Manganese equilibrium is achieved more slowly than sulphur equilibrium, and the manganese recovery indicates the degree of slag oxidation. The rate of desulphurization is affected chiefly by the basicity and degree of oxidation of the slag, the limiting reaction controlling the rate being the reduction of SiO_2. With the more acid slags, increasing the rate of stirring has little effect on the rate of desulphurization, and it is also noted that MgO is a poor desulphurizer, although equal to CaO in neutralizing acid constituents.—G. F.

Effect of Silica Reduction on the Desulphurizing Power of Blast-Furnace Type Slags. N. J. Grant, O. Troili, and J.

Chipman. (*Amer. Inst. Min. Met. Eng.*, 1951, Aug., 672–673; *J. Met.*, 1951, **3**, Aug.). This investigation is complementary to that of Grant, Kalling, and Chipman (*see* preceding abstract), the same experimental apparatus and procedure being used. It is shown that silica in the slag affects the desulphurizing reactions, and when sufficient silicon is present to prevent further reduction of silica, the transfer of sulphur from metal or slag is extremely rapid. It is also noted that distribution of silicon between slag and metal is an important factor meriting further study.—G. F.

The Effect of High Alumina Contents in Blast-Furnace Slags. H. Schrader. (*Arch. Eisenhüttenw.*, 1951, **22**, Sept.–Oct., 275–282). The influence of 25–30% alumina in blast-furnace slags, which is about twice the normal amount, manifests itself in a considerable decrease in the fluidity of the slag which, in acid slags, derives from the formation of the mineral $CaO.Al_2O_3.(SiO_2)_2$, and in basic slags from the formation of $(CaO)_2.Al_2O_3.SiO_2$. The alumina content of the portion of the slag contributed by the coke is 17–19%. A comparison of American and Indian blast-furnace practice shows that the high alumina content (26%) of Indian slags is to be ascribed to the alumina-rich ores employed. Basic compounds of high lime content, present in high-alumina slags, influence adversely the reduction of silica and desulphurization on account of their basicity, and fluctuations in the sulphur content of the iron from 0·036 to 0·063% can be ascribed to this source. Limiting the alumina content of the slag, increase in working temperature, and replacement of lime by dolomite in the burden (to increase the magnesia content of the slag), are recommended for combating the adverse effects of high alumina in the slag.—P. F.

Some Aspects of the Blast-Furnace Situation in the U.S.A. O. R. Rice. *J. Iron Steel Inst.*, 1952, **170**, Feb., 89–108). [This issue].

Blast Furnace Instrumentation. E. T. Mortson and S. T. Paisley. (Amer. Soc. Mech. Eng.: *Blast Furn. Steel Plant*, 1951, **39**, July, 789–799). The functions and operating details of the following instruments are given: Hot blast temperature indicator and recording controller; top gas temperature, furnace inwall, stove dome, and stove stack temperature recorders; cold-blast temperature indicator; cold-blast pressure indicator and recorder; furnace top pressure recorder; stockline recorders; cold-blast air flow recorder and large-bell movement recorder. There is a combustion regulator for each stove.—J. P. S.

Regulation of the Working of a Basic Blast-Furnace at Constant Wind Rate. P. Thierry. (*Rev. Mét.*, 1951, **48**, Aug., 619–630). The desirable characteristics of iron, the conditions of its production; and the fulfilment of the two functions of the furnace (production of iron and production of gas) are considered. The methods of furnace regulation at the throat and tuyeres of the furnace are discussed. From results of trials it is concluded that operation at constant blast gives iron of very constant composition with fewer incidents such as scaffolding, and thus increases production. For this type of operation the blowers and Cowper stoves must have reserves of power and heat respectively.—A. G.

Influence of Phosphorus on the Activity of Sulphur in Liquid Iron. J. Chipman and C. W. Sherman. (*Rev. Mét.*, 1951, **48**, Aug., 613–618). Samples of iron were kept at 1600° C. in a hydrogen-sulphide–hydrogen atmosphere and analysed for sulphur until equilibrium was reached. The activity coefficient of sulphur f_s in an iron of any composition can be found by the addition of the values of $\log f_s$ for each element present. Carbon, silicon, and phosphorus markedly increase the activity of sulphur.—A. G.

Extension of the Electric Pig-Iron Works at Choindez. E. Gehrig. (*Von Roll Werkzeitung*, 1950, **21**, Sept., 202–212). The works produces 50 to 80 tons of liquid iron in 24 hr. A 100-ton pig-iron mixer, which was installed in 1948, is described. A drawing of this mixer and a photograph of its hydraulic drive are given. The sintering plant and lime-kiln have sections devoted to them. A plan of the works is included.—E. C. S.

Blast Furnace Inwall Rebuild at Algoma. D. Joyce and J. Laidlow. (*Iron Steel Eng.*, 1951, **28**, Sept., 75–80). The authors describes the rebuilding of a 25-ft. hearth blast-furnace at Algoma Steel Corp. Ltd., Ontario.—M. D. J. B.

51,000 Tons of Danish Pig Iron Produced in 1950. S. Hedegaard and E. Ramsby. (*Dansk. Tekn. Tidskr.*, 1951, **75**, Feb., 39–43). [In Danish]. The F. L. Smidt process for production of cement and pig iron simultaneously in the same rotary kiln is outlined. The charge is composed of pyrite cinders, steel turnings, scrap, lime slurry, and coke fines. From 1939 to 1945, instead of adding imported iron ore to attain the proper manganese content, the Danish works used domestic bog ore. The price of the 51,000 tons of iron produced yearly would not be competitive but for the rearmament demand.—B. S. E.

TREATMENT AND USE OF SLAGS

The Problem of Blast-Furnace Slag in Poland. J. Nechay. (*Hutnik* (Warsaw), 1951, **18**, June, 227–229). [In Polish]. Possible uses of blast-furnace slags, depending on their chemical composition and method of cooling are outlined.

Properties of Blast-Furnace Slags Required by the Building Industry. H. Riess. (*Hutnik* (Warsaw), 1951, **18**, June, 234–335). [In Polish]. A classification of blast-furnace slags from the users' point of view is made.—V. G.

Foamed Blast-Furnace Slags. W. Sabela. (*Hutnik* (Warsaw), 1951, **18**, June, 244–249). [In Polish]. Properties of slags suitable for foaming, the production of foamed slags, and their utilization are described.—V. G.

Slag Wool. J. Korngut. (*Hutnik* (Warsaw), 1951, **18**, June, 249–252). [In Polish]. The technology of the production of slag wool with particular reference to the methods used in the U.S.S.R. is described.—V. G.

Granulation of Slag. Z. Jodlowski. (*Hutnik* (Warsaw), 1951, **18**, June, 253–256). [In Polish]. The methods of production of granulated slags are discussed.—V. G.

The Use of Blast-Furnace Slags as Fertilizers. W. Stoklosa. (*Hutnik* (Warsaw), 1951, **18**, June, 256–275). [In Polish]. Blast-furnace slags contain all the macro and micro elements in suitable proportions for plant life, and their use as fertilizers is advocated.—V. G.

The Causes of the Instability of Blast-Furnace Slags. W. Sabela. (*Hutnik* (Warsaw), 1951, **18**, June, 258–259). [In Polish]. Causes of instability of blast-furnace slags, such as allotropic transformation of calcium orthosilicate, hydrolysis of ferrous and manganous sulphides, and methods of testing are outlined.—V. G.

The Development of the Production of Road Blocks from Blast-Furnace Slags in the U.S.S.R. A. Ofiok. (*Hutnik* (Warsaw), 1951, **18**, June, 260–261). [In Polish]. Moulds and method of making road blocks from blast-furnace slags in the U.S.S.R. are described.—V. G.

The Possibilities of Using Granulated Blast-Furnace Slags from Old Slag Heaps to Produce Hydration-Bond Binders. A. Ofiok. (*Hutnik* (Warsaw), 1951, **18**, June, 261–265). [In Polish]. The author reviews investigations on old blast-furnace slag which had as their object utilizing it to produce hydration-bond binders.—V. G.

PRODUCTION OF STEEL

Recent Developments at the Sydney Steel Plant. N. A. Parlee. (*Canad. Min. Met. Bull.*, 1951, **44**, June, 382–387). Developments in the Dominion Iron and Steel, Ltd., plant, Cape Breton Island, are outlined. Improvements include better mining methods for ore, coal, and limestone. New plant includes a battery of 53 Kopper's Becker coke ovens and ancillary equipment. Two of the three blast-furnaces have had carbon hearths since 1948. Large-scale reorganization, and replacement of gas by oil firing in the open-hearth department took place between 1947 and 1950. Rolling-mill plant has been improved, and new Vaughan H.C. wire-drawing machines are on order. Research has been carried out on coal preparation, by-product recovery, utilization of blast-furnace slag, the use of oxygen in steelmaking, and other problems.—T. E. D.

Steel Company of Wales. (*Sheet Metal Ind.*, 1951, **28**, Sept., 789–798). A brief description is given of the new Margam and Abbey Works of The Steel Company of Wales Ltd., opened on July 17, 1951. (*See J. Iron Steel Inst.*, 1951, **169**, Dec., 399).—P. M. C.

Losses in the Form of Smoke in the Basic Converter Blow. W. Pepperhoff and F. Zirm. (*Arch. Eisenhüttenw.*, 1951, **22**, Sept.–Oct., 295–297). Losses due to the escape of iron-oxide smoke during the blow of basic converters were determined by an optical method. Electron micrographs of smoke particles deposited on an electron-transparent membrane, show the particles to have a mean diameter of 55 mμ. On the basis

of theoretically evaluated absorption of light of a single particle of such diameter, and the experimentally determined absorption of the converter smoke, the number of particles lost in the smoke during the blow was determined, and the losses by the escape of the smoke estimated at 0·02%, by weight, of the charge.—P. F.

Manganese, the Controlling Element in the Manufacture of Basic-Bessemer Steel. V. Remond. (*Rev. Techn. Luxembourg.*, 1951, **43**, July–Sept., 135–143). In 1914 steelworks were producing steel with 3% Mn. Between 1919 and 1939 this fell to about 1·10%. Desulphurization with sodium carbonate made this possible. This technique has revolutionized basic practice. The author reviews the practice at Corby, England, and its application to French problems. The author considers that when the alumina in the blast-furnace slag exceeds 18% the addition of manganese to the burden is justified.—B. G. B.

Zebra Type Open-Hearth Roof Steps Up Heats per Campaign. (*Steel*, 1951, **128**, May 7, 126–128). Of the open-hearth furnaces in the U.S.A. 32% are now using roofs incorporating alternate courses of silica and basic bricks. Opinions on this practice differ, but increases up to 41% in the number of heats per campaign are reported.—A. M. P.

Hot Metal Cars and Mixers. R. P. Heuer and C. E. Grigsby. (*Steel*, 1951, **128**, Apr. 2, 93–96; **129**, July 16, 82–88; Aug. 6, 90–97; Aug. 20, 78–84). The authors discuss the effect of service conditions on the life of hot metal cars and mixers. Small increases in ladle temperature and concentration of reducing gases in the ladle atmosphere may considerably increase the slag fluidity. Normally a mixer roof temperature controlled at 2150–2250° F. and a reduction of temperature of iron and slag in hot metal cars will increase lining life. The theory is advanced that an increase in the tons of metal put through a ladle per day will give an increase in tonnage per lining. The authors discuss how equipment design, brick size, mortar quality and type of bricklaying affect the life of the lining. Where conditions are not unusually severe, a dense, stiff, high-duty fireclay brick laid in sillimanite mortar is most economical. New blast-furnace and super-duty fireclay bricks are also considered. The experiences of several steel companies with various refractory materials are examined. Unburned magnesite-chrome bricks, used in mixers for campaigns up to 19 months are suggested for lining hot metal cars.—M. D. J. B.

A Method for Handling Steelmaking Slag. (*Iron Steel Eng.*, 1951, **28**, Oct., 85–89). This article describes a method developed by the Consett Iron Co., Ltd., to improve the handling of flushing slag. It consists in granulating the steelmaking slag and also provides—with its 15% Fe, CaO, and MnO contents—an ideal material for sintering and adding to the blast-furnace charge. The possibilities of using the process in the U.S.A. are considered.—M. D. J. B.

Open Hearth Charge Ore : Key to Steel Capacity Expansion. L. B. Lindemuth. (*J. Met.*, 1951, **3**, Aug., 592–596). The author advocates the increased use of open-hearth charge ores to compensate for the diminishing supplies of steel scrap, and discusses the steelmaking conditions that will permit this. The important characteristics of charge ores are considered, and the effect of variation of these properties on the steelmaking practice and ingot yield is discussed. Finally, a description is given of the Hannah Furnace Corporation's rotary kiln pilot plant for the preparation of suitable charge ores. The plant has successfully treated all types of fine ores available, with good control of the critical properties.—G. F.

Desulphurizing Action of Titanium in Steels. W. P. Fishel, W. P. Roe, and J. F. Ellis. (*Amer. Inst. Min. Met. Eng.*, 1951, **3**, Aug., 674–676; *J. Met.*, 1951, Aug.). The authors describe an investigation of the distribution of sulphur between iron and titanium in alloys of the Fe–Ti–S and Fe–Ti–C–S systems. It is shown that the sulphide TiS is formed, existing as a separate phase below 1000° C. Titanium is found to react with sulphur in preference to carbon, and can replace manganese in fixing sulphur and preventing the formation of FeS.—G. F.

The Metallurgy of Chromium in the Basic Steel-Making Process. E. Plöckinger. (*Arch. Eisenhüttenw.*, 1951, **22**, Sept.–Oct., 283–293). The metallurgical behaviour of chromium, particularly its reactions with iron-oxide-bearing calcium-silicate slags, was investigated using samples taken from melts in basic electric and open-hearth furnaces. In the region in which the CaO/SiO_2 ratio of the basic slags exceeded 2, the equilibrium constant of the oxidation of chromium, and its temperature dependence, were determined, thus facilitating the mathematical treatment of the chromium/basic-slag reaction. Examples of the practical application of the relationships discovered are given. The partition coefficients of chromium and of manganese in the slag-melt system, as functions of the total iron oxide in the slag, are shown graphically for the basic and acid processes. In the transition region between the truly basic and acid processes qualitative indications are given. A comparison of the experimental results with those determined from thermodynamic data shows satisfactory agreement if the calculations are carried out on the basis of the free energies of reaction of the individual reactions involved. Recent thermochemical data show that the reactions of chromium in basic steelmaking require a wide range of heats and entropies of activation. They thus exemplify the necessity of taking entropy changes into account in the interpretation of reactions associated with the production of alloy steels if errors, liable to amount to several orders of magnitude, are to be avoided.—P. F.

Measurement of Air Infiltration in Open-Hearth Steel Furnaces. R. Haynes. (*J. Iron Steel Inst.*, 1952, **170**, Feb., 149–152). [This issue].

Melt Control in Basic Open-Hearth Furnaces. T. V. S. Ratnam. (*Tisco Rev.*, 1951, **19**, Apr., 382–384). The author discusses the practical aspects of melt control. The important variables, scrap/hot-metal ratio, silicon content of hot metal, period from beginning of scrap charging to addition of hot metal, and the limestone in the charge, are correlated with a view to controlling the carbon at 'melt down.' By converting the silicon, manganese, and phosphorus to equivalent carbon values, the total scrap and bath oxidation during the melting period is calculated. Data on the carbon at 'melt down' and limstone charges for scrap/hot-metal ratios between 70/30 and 30/70 with the silicon in the hot metal varying from 0·7% to 1·7% are presented.—E. T. T.

The Use of Lime, Limestone and Dolomite in Iron and Steel Manufacture. (*Edgar Allen News*, 1951, **30**, July, 901–903). In addition to that part of the article covered by the title, the principal uses of lime outside the iron and steel industry are listed. The history of the lime-producing firm S. Taylor Frith and Co., Ltd., Dove Holes, is traced. An Edgar Allen rotary dryer is employed by this Company.—E. C. S.

Oxygen in the Iron and Steel Industry. J. Natkaniec. (*Hutnik* (Warsaw), 1951, **18**, May, 204–210). [In Polish]. The use of oxygen in open-hearth furnaces is discussed.—V. C.

Diffusion Deoxidation with Coke in the Basic Open-Hearth Furnace. K. Radzwicki and J. Kozielski. (*Prace Gtównego Inst. Met.*, 1951, **3**, 4, 267–278). [In Polish]. Deoxidation of the bath with coke in the basic open-hearth furnace is discussed. The procedure was as follows: When the necessary degree of decarburization was obtained, coke breeze or fines were thrown on to the slag. Deoxidation of the slag caused oxides from the metal to diffuse into the slag. Tnis coke addition was repeated three times and the steel then finished in the usual manner. The results for 18 heats in a 50-ton furnace with coke deoxidation are given. The following conclusions are drawn: (1) Diffusion deoxidation is more efficient than deoxidation by precipitation; (2) addition of coke to the slag during deoxidation does not cause recarburization of the bath, nor the return of phosphorus from slag to metal; (3) the quality of metal is improved so that steel deoxidized by this diffusion method has properties similar to those of electric furnace steel; (4) the iron oxide content of the slag is diminished; (5) when the decarburization process is intensified during the oxidation period, diffusion deoxidation does not increase the heat time; and (6) diffusion deoxidation considerably reduces deoxidizer and ferro-alloy consumption; the manganese losses in deoxidation are reduced by 50%—V. G.

Tool Steel Scrap Key to Metal Conservation. H. M. Givens, jun. (*Steel*, 1951, **128**, June 11, 101). The author recommends that to conserve scrap it should be grouped into four classes: (1) High-tungsten type; (2) M-2 tungsten–molybdenum type; (3) high-molybdenum type; and (4) cobalt-bearing type. Segregation is essential since alloys containing nickel, copper, lead, or tin contaminate high-speed steel scrap and make it worthless.—M. D. J. B.

Principles Underlying Refining Processes. F. D. Richardson. (Principles of Extraction and Refining of Metals; *Inst. Met.*, Mar., 1951, 83–102). In this paper the pattern of atomic

and molecular interaction which is found in refining processes is discussed. The author deals in particular with systems related to fire refining by distillation or by means of slags. The value of the application of thermodynamics in these processes is emphasized.—J. A. L.

Fundamentals of the Production of Metal and Alloy Ingots. L. Northcott. (Principles of Extraction and Refining of Metals; *Inst. Met.*, Mar., 1951, 53–82). The author first considers the properties of the liquid metal, dealing in particular with gas-removal methods. He then discusses mould materials, dressings, temperature, and shape. The casting operation is next considered, and lastly the properties and structure of the ingot.—J. A. L.

Open-Hearth Furnaces 'Jet Tapped' in 30 Seconds. (*Steel*, 1951, **128**, Apr. 30, 64–67, 78). E. I. du Pont de Nemours and Co., Wilmington, Del., have produced a 2-ounce 'shaped' explosive charge for open-hearth tapholes which will penetrate up to six inches of cold steel. This and its advantages are described.—A. M. F.

Refining by Crucible. (*Aciers Fins et Spéc. Franç.*, 1951, July, 41–42). This process cannot compete with others on the grounds of production and tonnage but it combines accuracy and laboratory perfection with mass production. The influence of the previous development of the metal and the steady fusion isolated from oxidation permit a very high-quality product.—E. C. S.

Arc Furnace Capacity. (*Steel*, 1951, **129**, June 30, 74–78). The increase in production of electric steel in the last 30 years is discussed and it is shown how, despite some serious drawbacks in the technique, by this method steelmaking capacity can be increased more quickly than by open-hearth or Bessemer converters. It is claimed that many electric furnace shops can now compete with open-hearths using the cold-melt process for producing rimming steels of ordinary carbon grades.—M. D. J. B.

Distribution of Hydrogen in Large Ingots and Forgings. J. D. Hobson and C. Sykes. (*J. Iron Steel Inst.*, 1952, **170**, Feb., 118–122). [This issue].

Vertical Solidification of Steel Ingots Studied. J. W. Spretnak. (*Iron Age*, 1951, **167**, May 3, 107–110). The kinetics of vertical solidification and its extent in ingots are described. It is pointed out that heat removal in transverse solidification occurs by radiation while in vertical solidification both radiation and conduction take place, and an equation for this vertical solidification is postulated. Solidification times using this equation are compared.—A. M. F.

Surface Defects in Ingots and Their Products (Recommended Definitions). (*Iron Steel Inst., Special Report No.* 44, Aug., 1951). This report, by the Ingot Surface Defects Sub-Committee of the Steelmaking Division of the British Iron and Steel Res. Assoc., contains recommended definitions with photographs of examples of defects occurring in ingots and the semi-finished and finished products of ingots.—R. A. R.

Testing Hot Metal Ladles. K. E. Knudsen, W. H. Munse, and B. G. Johnston. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, 11–18). The authors describe test procedures applied in structural tests of hot-metal ladle models. These were made to a one-fifth scale of actual 150-ton capacity ladles, and mercury was used to load the models instead of molten steel. Strains and deflections produced during filling, tilting, and pouring were determined by electric resistance strain gauges and dial gauges.—P. M. C.

Growth of Cast Irons. Application to the Study of the Growth of Ingot Mould Irons. P. Rocquet and M. Olette. (*Fonderie*, 1951, **67**, July, 2565–2577: *Iron Steel Inst., Translation Series*, No. 427, 1951).

PRODUCTION OF FERRO-ALLOYS

Manganese Concentration from Low Grade Domestic Ore: Nossen Nitric Acid Cycle. E. S. Nossen. (*Indust. Eng. Chem.*, 1951, **43**, July, 1695–1700). Details are given of a pilot plant for recovering manganese from low-grade ores (5–20% manganese). The plant works on the Nossen nitric acid cycle, which permits the separation of manganese from iron, silica, and other undesirable impurities, and the decomposition of the manganese nitrate solution which is formed, directly to manganese dioxide and nitric acid. Manganese recovery is satisfactory in many ores that were formerly inaccessible to treatment. A nitric acid recovery of more than 95% is obtainable. Other metals combined in the ore can be recovered in an inexpensive way. Details of the economics of the process are given.—C. J. B. F.

Manual Handling Eliminated in Ferroalloy Plant. L. C. Hopper. (*Iron Age*, 1951, **167**, Apr. 26, 96–97). Industrial power trucks are used to transport racks loaded with alloying briquettes from the forming machines to the drying rooms and thence to the bulk storage bins. Novelties include a tiltable unloading mechanism, operated by the driver of the truck, for emptying the racks, and a tilting platform 'tote box' for conveying the finished product from storage to railway wagons.—A. M. F.

FOUNDRY PRACTICE

Grey Ironfounding. (*Anglo-American Council on Productivity*, Sept., 1950). This 125-page report describes what was seen by the British team which visited 24 grey iron foundries in the U.S.A., and presents the team's conclusions.—R. A. R.

Scrap Down, Quality Up, Through Statistical Control Systems. H. H. Johnson. (*Steel*, 1951, **128**, May 21, 76–79, 98–103). By measuring the 'process capability' of many of the most important steps in foundry operation, scrap losses have been reduced, quality improved, and production increased. Three classes of control chart are described: (1) Measurement charts, made up of measurements taken during the process, of such variables as chemical analyses, sand properties, mould hardness, core dimensions, etc. (2) Those based on variables such as physical properties of the steel produced, casting dimensions, fit of moving parts, and similar aspects of the product. (3) Those called 'fraction defective charts' giving a picture of the amount and rate of occurrence of defective castings.—A. M. F.

Foundry Operating Procedure Standards. M. J. Kellner. (*Foundry*, 1951, **79**, July, 90–91). Foundry operational efficiency and quality of products are said to have suffered with increased mechanization because of the decline of pride of craftsmanship. An operating procedure, adopted by workers and supervisors, designed to combat this human element is introduced.—E. J. D. S.

Foundry Developments in the Second Half of 1950. P. A. Heller. (*Stahl u. Eisen*, 1951, **71**, Sept. 13, 1011–1014: Sept. 27, 1058–1063). The literature is reviewed. (81 references).

The Casting of Aluminium on to Iron and Steel by the Al-Fin Method. H. Kalpers. (*Metall*, 1951, **5**, Oct., 444–446). The author describes the Al-Fin process, patented by the Fairchild Engine and Airplane Corp., which consists in dipping the steel or cast iron article in molten aluminium so as to cause the formation of $FeAl_3$ between the two metals, followed by casting on proper. Fields of application are listed; they take advantage of the strength of the steel and the thermal conductivity of aluminium.—J. G. W.

Need Stronger Foundry Coke. H. W. Lownie, jun. (*Foundry*, 1951, July, **79**, 72–76). A report from extensive commercial and laboratory trials on cupola cokes is discussed. The main conclusion is that coke strength is the best measure of coke performance in a cupola. The possibility of using hot blast economically partly to offset the disadvantages of poor coke is introduced.—E. J. D. S.

Zirconium Alloy as Manganese Substitute in Gray Cast Iron. W. C. Jeffery. (*Amer. Foundryman*, 1951, **20**, Aug., 46–50). Small ladle or cupola additions of zirconium as Zr–Fe–Si alloy to grey cast iron were effective in controlling sulphur, and are reported to form sulphides more readily than manganese. Hardness and the tendency to chill were reduced, and machinability increased. This zirconium alloy appears to be a satisfactory substitute for the commonly used manganese inoculant.—E. J. D. S.

Development Trends in Cupola Construction. J. Drachmann. (*Gjuteriet*, 1951, **41**, June, 83–88). [In Swedish]. Chemical equilibria are never reached in the cupola process, and the author makes recommendations with a view to obtaining constant conditions, with special reference to water cooling, basic slag, preheated blast, and oxygenated blast.—B. S. E.

Cupola Melting. R. W. Ruddle. (*Inst. Australian Foundrymen: Australasian Eng.*, 1951, Aug. 7, 84–88). The author submits that very few cupolas are operated efficiently, due to lack of knowledge of fundamentals. The first essential is to supply the correct volume of air, evenly distributed and at the correct velocity to burn the correct amount of coke necessary to melt the required amount of iron. The effects of cupola and tuyere design, grade of coke,

and air humidity on the attainment of these ideal working conditions, coke bed height, slag composition and control, and tapping procedures are discussed.—P. M. C.

Preheating Cupola Blast. W. von Preen. (*Gjuteriet*, 1951, **41**, Aug., 117–121). [In Swedish]. Piwowarsky's considerations of the several advantages of preheated cupola blast are quoted and illustrated by heat-flow diagrams.—B. S. E.

Quenching Coke after Emptying a Cupola. S. Pelczarski. (*Przeglad Odlewnictwa*, 1951, **1**, June, 170–172). [In Polish]. The author describes a simple installation to reduce fumes and dirt when blowing out a cupola. This consists of a pit underneath the cupola with a covered side trench for removing the quenched coke. The water for quenching is led into the bottom of the pit by a pipe fitted with a sprayer. After emptying the cupola into this pit by opening the bottom doors, the water is slowly turned on. Steam formed on contact with hot coke passing upwards through successive layers cools it quickly owing to the strongly endothermic water-gas reaction. The hydrogen and CO formed are burned over the coke and escape into the open cupola together with a small amount of steam.—V. G.

The Stürzelberg Pig-Iron Refining Process. H. Reinfeld. (*Giesserei*, 1951, **38**, Oct. 4, 517–523). A full description is given of high-grade pig-iron manufacture at Stürzelberg, the raw material being roasted pyrites containing 8–10% of zinc and 4–7% of sulphur.—J. G. W.

High Duty Cast Irons. L. Sanderson. (*Eng. Boiler House Rev.*, 1951, **66**, June, 173–177). The new high-duty cast irons are usually made by the inoculation method of which the principal advantage is that it enables the founder to control the combined carbon content at the cupola spout without modifying the charge. A graphite flake which is short and curly is produced in the structure, thus making the iron extremely strong and more corrosion resistant. Today, a standard specification is 30 tons/sq. in. tensile strength. A few typical cupola charges are given.—E. C. S.

Study on the Nodular Graphite Cast Iron. (2nd Report)—On the Graphite Nodulizing Magnesium Alloys. T. Tanaka, A. Muramatsu, and T. Hayakawa. (*J. Mech. Lab.*, 1950, **4**, No. **3**, 97–101). [In Japanese]. Various alloys of magnesium, which would give more constant recovery of magnesium and less reaction during the addition to molten iron, were investigated. The alloys include ferrosilicon, and silicon, aluminium, tin, zinc, and copper alloys of magnesium.—T. E. D.

Applying Research Findings in the Malleable Iron Shop. J. E. Rehder. (*Amer. Foundryman*, 1951, **20**, July, 51–56). Some important aspects of melting and annealing are summarized. The accidental occurrence of tin to the extent of 0·07% can render malleable iron unannealable. Comments on the functions of oxygen and sulphur in malleable iron melts are offered. It is suggested that there is no metallurgical justification for lowering the sulphur contents, apart from a slight saving in manganese, and that no disadvantages appear from operating at 0·18% sulphur provided that it is balanced by the appropriate amount of manganese. Furnace additions of ferromanganese have a mottling effect, whilst high tapping temperatures tend to offset this disadvantage. High tapping temperatures enable the iron to be annealed more rapidly, but may result in the reduction of silica from the lining by carbon, this reaction becoming appreciable at about 2820° F.—E. J. D. S.

Planning Tests for Producing Black-Heart Malleable Cast Iron on an Industrial Scale. J. Piaskowski. (*Przeglad Odlewnictwa*, 1951, **1**, July–Aug., 200–206). [In Polish]. Projected experiments leading to the production of black-heart malleable cast iron and practical advice on conducting trials are described.—V. G.

Steel Founding. (*Anglo-American Council on Productivity*, Sept., 1949). This is a report (108 pages) by a productivity team representing the British Steel founding industry which visited steel foundries in the U.S.A. in 1949.—R. A. R.

Cast Stainless Steel in Ceramic Molds. H. Czyzewski, R. L. Cook, P. Frederick, and J. P. Jero. (*Amer. Foundryman*, 1951, **20**, July, 38–39). The following mould compositions were dry-pressed at 3545 lb./sq. in. and fired: (1) 50% calcined fireclay and a blend of high-grade fireclays: Seger cone 6. (2) Steatite, composed of a high proportion of talc with 15% clay: cones 9, 11, 14. (3) Cordierite, a special blend of talc, alumina, and clay which had low expansion characteristics: cones 9, 11, 14. (4) 75% pulverized alumina, balance ball clays: cones 14, 15; (5) zircon porcelain, containing a high proportion of ground zircon with clay and complex alkaline earth zirconium silicates. Firing time was 16 hr. Stainless-steel tensile test specimens were cast in these materials, although the threaded portions were not satisfactory after the moulds were used the first time. Only moulds of No. 1 material were preheated, but the mechanical properties of the cast bars were unsatisfactory when the moulds were preheated to 1000° F. This behaviour was attributed to porosity from entrapped gases.—E. J. D. S.

Effect of the Melting Procedure in Basic Open-Hearth Furnaces on the Quality of Steel Castings. J. Kozielski. (*Przeglad Odlewnictwa*, 1951, **1**, Sept., 253–257). [In Polish]. Defects in steel castings and their causes are discussed. Recommendations as to the best melting procedure for steel castings are given.—V. G.

New Developments in the Production of Steel in Side-Blown Converters. J. Natkaniec. (*Przeglad Odlewnictwa*, 1951, **1**, July–Aug., 213–226). [In Polish]. The advantages of side-blown converters and the use of oxygen-enriched flash are discussed.—V. G.

Factors Affecting Oil-Sand Core Baking. H. W. Dietert. (*Amer. Foundryman*, 1951, **19**, May, 67). Variable factors in the baking of test cores are discussed. For example, the exhaust pipe of the oven should extend through the roof of the building to at least 5 ft. above any adjacent building projection in order to avoid eddy currents which can interfere with the exhaust system. The use of a chromium-plated reflector plate below the baking tray to facilitate uniform baking of the samples, and the variations in tensile strength attributable to humidity are discussed.—E. J. D. S.

Bentonite Bonding Properties Affected by Drying Temperature and Moisture Content. F. L. Cuthbert and T. M. Dyer. (*Amer. Foundryman*, 1951, **19**, June, 50–51). Results of a series of tests are reported to show the effects of drying temperatures, time, moisture content, and relative humidity on the initial properties of bentonites and the compression strengths of sands bonded with it. Sands containing 4% western bentonite on a dry basis can be heated to about 400° C. without harming either green or dry compression strength, although dry strength appeared to be slightly more sensitive to high temperatures than green strength.—E. J. D. S.

Core Strength Variations Due to Oven Humidities. H. W. Dietert and A. L. Graham. (*Amer. Foundryman*, 1951, **20**, July, 58–59). Core strength variations and the quantities of binders necessary have been reduced by establishing absolute humidity values in core-oven atmospheres. Once the optimum value has been determined, the core-oven atmosphere controls can maintain it. Maximum strength in the reported tests was reached when the absolute humidity was slightly less than 60 grains of moisture per pound of dry air.—E. J. D. S.

Factors Governing Sea Coal Selection and Control. E. C. Zirzow. (*Amer. Foundryman*, 1951, **19**, June, 45–47). Pulverized coal and sea coal are added to moulding sands in order to: (*a*) Prevent the burning-on of sand on the casting surface; (*b*) improve appearance of the casting; (*c*) make a more thermally stable sand, thereby eliminating scabs and buckles; and (*d*) control metal shrinkage. These four objectives are discussed in the light of the behaviour of coal particles when the mould is filled.—E. J. D. S.

Problem in Gray Iron Molding. J. W. Birks. (*Amer. Foundryman*, 1951, **19**, June, 34–37). Pattern design, sand moulds, and cores, with the appropriate gating and venting technique, are described for a grey-iron casting for distilling plant.—E. J. D. S.

Zircon Sand Properties and Uses in Cores and Facings. A. Smith. (*Amer. Foundryman*, 1951, **19**, May, 64–67). Zircon sand can be employed for making all types of moulds and cores. Although the initial cost of zircon sand is more expensive than that of ordinary sand the extra cost can be recovered. Since this sand can be used to provide small chills or to face metal ones, savings can be effected by the much increased chill life and the reduced machining costs. Because zircon sands are fine and the grains rounded, the mixes are usually less permeable than those of silica sand. Sources of gas such as core oils and water should therefore be kept to a minimum.—E. J. D. S.

Home-Made Devices Give Core Work Economies. H. Chase. (*Iron Age*, 1951, **167**, Apr. 19, 95–98). One of the major economies in core making, at the grey iron foundry of the Buick Motor Division of General Motors Corp. has been the development of simple machines for removing fins from cores.

A die consisting of a flat mat of rubber moulded to an interior contour fitting that of the core at the plane where the fins occur is used. Automatic dipping of green cores and new conveyors and handling methods also cut labour costs and reduce breakage.—A. M. F.

Fundamental Problems in Preparing Moulding Materials. W. Chabowski. (*Przeglad Odlewnictwa*, 1951, **1**, Sept., 257–263). [In Polish]. The regeneration of spent moulding materials is discussed.—V. G.

The Use of Green Cores in Steel Foundries. K. Lohner. (*Przeglad Odlewnictwa*, 1951, **1**, July-Aug., 191–200). [In Polish]. The following advantages of making steel castings with green cores are discussed: Economy in fuel, space, and man-hours; simplification of the moulder's and core maker's work; and the reduction in the number of faulty castings. The production of green cores is outlined. Examples of different arrangements of mould and core, and methods of degassing, reinforcing cores, and tables of faults in castings, their causes and prevention are given.—V. G.

Gas Evolution from Molds and Cores. W. H. Moore. (*Foundry*, 1951, **79**, July, 80–87). Factors influencing the evolution of gas from moulds and cores, including moisture and underbaking, and their effect on castings were investigated. A simple apparatus for measuring the rate of gas flow from various sand mixes was employed, details of which are given.—E. J. D. S.

Study on Surface of Casting. IV. (Roughness of Green Sand Mold and Casting). K. Katori, T. Okakura, and K. Hashimoto. (*J. Mech. Lab.*, 1950, **4**, No. 3, 126–136). [In Japanese]. After measuring the surface roughnesses of green sand moulds by the light cross-section method, these results were compared with measurements on the surface of the castings. The technique employed is described and results are given for various grain sizes of sand used in the moulds.—T. E. D.

Planning a Moulding Shop. R. Chudzikiewicz. (*Przeglad Odlewnictwa*, 1951, **1**, Sept., 247–252). [In Polish].

Gating Principles Applied to Gray Iron Castings Produced on Match Plates. A. J. Howarth. (*Amer. Foundryman*, 1951, **20**, July, 28–32). A series of 12 illustrations is presented and discussed for the purpose of demonstrating the principles controlling the design of gates, runners, sprues, and risers to produce sound castings.—E. J. D. S.

Wedges Effective in Fastening Pins and Clamps. P. Dwyer. (*Foundry*, 1951, **79**, July, 98–99). Three useful wedge devices for clamping flasks are described.—E. J. D. S.

Machines Make Shell Molds Automatically. W. Czygan. (*Iron Age*, 1951, **167**, Apr. 19, 81–85). The development of the technique of shell-moulding is described and details of a machine capable of producing automatically 50 to 60 complete moulds per hour are given. Details of the resin/sand ratios and temperatures used for large-scale production are still secret.—A. M. F.

The Production of a 10,000 Kg. Chilled Iron Roll. G. Born. (*Von Roll Werkzeitung*, 1951, **22**, Mar., 69–71). The production of a very large chilled iron roll at the von Roll works is described and illustrated.—E. C. S.

How to Set up a Precision Casting Foundry. W. F. Davenport and A. Strott. (*Iron Age*, 1951, **167**, Apr. 19, 90–94). The methods of making dies and patterns for small precision castings are described and details of a new type of pre-coat containing 30% Al_2O_3 are given. This coating produces castings that break out of the mould without refractory material or oxide adhering to the surface.—A. M. F.

The Development of Various Centrifugal Casting Processes for the Production of Cast Iron Pipes 1914-1950. E. Gehrig. (*Von Roll Werkzeitung*, 1951, **22**, Mar., 63–69). The basic requirements of the Sensaud-Arens process developed by D. Sensaud de Lavaud and F. Arens, are: (1) A cold rotating permanent mould; (2) immediate drawing of pipe after solidification; (3) use of very hot iron; and (4) the iron must contain 1·8–2·5% Si. A drawing of the Sensaud-Arens pipe-casting machine is given. Later these two workers developed independent processes and even more recently W. D. Moore developed the Sandspun process.—E. C. S.

Manufacture of Centrifugally Cast Iron Pipe. (*Indust. Heating*, 1951, **18**, June, 1008–1018). The technique for centrifugally casting iron pipe at the American Cast Iron Co., is described. Two processes are used, the Mono-cast, which uses refractory or sand-lined moulds and requires no annealing, and the de Lavaud process which utilizes water-cooled moulds. A description of the Mono-cast process is given.—J. A. L.

Some Recent Developments in Centrifugal Casting. M. L. Samuels and A. E. Schuh. (*Foundry*, 1951, **79**, July, 78–79, 218–224; Aug., 84–89). A review of modern metal-mould centrifugal casting practice is presented. Particular emphasis is placed on dual-metal castings including those of dissimilar metals such as steel and cupro-nickel.—E. J. D. S.

Precision Casting by the Lost-Wax Method. L. Luśniak. (*Przeglad Odlewnictwa*, 1951, **1**, July–Aug., 207–212). [In Polish]. An historical survey of precision casting is given and present technique is described.—V. G.

Investment Casting Conserves Critical Materials. R. L. Wood and D. von Ludwig. (*Steel*, 1951, **128**, May 14, 80–82). It is shown that investment casting can save alloys by transforming metal into finished parts with a minimum of conversion waste. Rules for the detailing or redesign of parts, by which maximum advantage of the material saving features can be obtained, are given.—A. M. F.

Foundry Modernization Expands Gray Iron Casting Capacity. (*Steel*, 1951, **128**, Apr. 30, 60–62). The foundry mechanization programme in the National Supply Co.'s Engine Division Plant at Springfield, Ohio, is described. Mechanization is one of the principal factors and a unique integral retractable boom system for supporting the bottom buckets for the cone-bottom charging system is used for charging the two cupolas. Improvements have been made in the mechanical handling of core and mould sand, and the moulds are rammed by centrifugal force.—A. M. F.

70 Million Castings in 243 Days. W. Czygan. (*Iron Age*, 1951, **167**, June 14, 89–91). Efficient handling and extensive mechanization enable the Foundry Division of the Eaton Manufacturing Co., Vassar, Mich., to produce a huge number of grey iron castings. Special skips facilitate carrying and dumping of lift truck loads, and the use of hoppers plays an important part in handling castings.—A. M. F.

A Visit to an English Iron and Steel Foundry. O. Carlsson. (*Gjuteriet*, 1951, **41**, June, 89–93). [In Swedish]. The foundries of Lake and Elliot, Ltd., Braintree, Essex, are described.—B. S. E.

The Measurement of the Casting Properties of Metals and Alloys. R. Guillemot. (*Fonderie*, 1951, **65**, May, 2459-2466). The author describes a method for studying casting properties, using a plumbago crucible divided into two compartments. One compartment contains the standard and the other the metal under investigation. Armco iron is the standard for ordinary and special steels.—R. S.

Stripping, Cleaning, Degassing, Desulphurizing, and Pipe-Suppressing Substances for Non-ferrous Metals, Cast Iron and Cast Steel. E. Piwowarsky. (*Giesserie*, 1951, **38**, Sept. 6, 417–422). The author discusses these substances with reference to recently published material on non-ferrous metals and his own investigations on cast iron and steel.—J. G. W.

Watch Your Cast Iron Chills! F. E. Sutherland. (*Amer. Foundryman*, 1951, **19**, May, 55–59). The constant use of the same set of cast-iron chills results in severe gassing of iron castings. Metallographic evidence indicates that this is caused by the removal of free carbon from the chill by reaction with iron oxide to give carbon dioxide. The gassing increases with the repeated use of the chill and it is concluded that to ensure gas-free castings, when conditions are otherwise satisfactory, chills should not be used more than three times. The use of graphite-free washes, and low-free-carbon irons and steel for chill materials should lengthen chill life.—E. J. D. S.

Casting Surface: Volume Ratio Predicts Gray Iron Properties. F. W. Kellam and H. H. Fairfield. (*Amer. Foundryman*, 1951, **20**, Aug., 30–32). The construction of a reference chart from which strength, hardness, and machinability can be predicted is described. This chart is based on data obtained from stepped blocks of the various irons used.—E. J. D. S.

Cleaning Iron Castings at Norrahammars Bruk. G. Fernheden. (*Gjuteriet*, 1951, **41**, July, 99–102). [In Swedish]. The layout of the cleaning shop at one of the larger Swedish foundries is sketched, and some special cleaning equipments are shown.—B. S. E.

The Volume Growth of Grey Cast Iron. M. Itzel. (*Gjuteriet*, 1951, **41**, Aug., 113–116). [In Swedish]. The main causes for volume growth of grey cast iron are confined to oxidation of silicon and iron, decomposition of cementite, and expansion cracking. Structural influence of graphite and silicon is demonstrated by the reduced growth in nodular iron.—B. S. E.

Records Are Basis of Quality Control in Smaller Foundry. A. D. Barczak. (*Amer. Foundryman*, 1951, **20**, July, 46–48).

A detailed programme of procedure, in which tags or forms are used for instructions and records, is outlined for pattern preparation, sands, and inspection.—E. J. D. S.

Statistical Quality Control. H. H. Johnson. (*Foundry*, 1951, **79**, July, 92–97, 189–191). The initial construction and subsequent maintenance of process control, product measurement, and charts of defective products are described. By these expedients both management and labour can be given an up-to-date picture of foundry performance and faults may be traced to their source.—E. J. D. S.

Absorbing the Technical Trainee. C. L. Carter. (*Amer. Foundryman*, 1951, **19**, June, 52–54). The need for a decisive policy to cover the intake and training of selected personnel for foundry supervisory positions is emphasized. Sources of recruitment (American), and two training programmes to provide for the conditions existing in large or small firms are detailed.—E. J. D. S.

Industrial Engineer in The Foundry. D. C. Williams. (*Amer. Foundryman*, 1951, **19**, May, 88–90). The author discusses the part which an industrial engineer can play in the foundry industry.—E. J. D. S.

Mechanical Engineer in the Foundry. L. C. Price and C. C. Sigerfoos. (*Amer. Foundryman*, 1951, **20**, July, 60–62). Foundry personnel requirements are analysed and the suitability of mechanical engineers and their training for various types of foundry work are discussed.—E. J. D. S.

HEATING FURNACES AND SOAKING PITS

Heat Application Fundamentals. M. H. Mawhinney. (*Amer. Gas Assoc.*: *Indust. Heating*, 1951, **18**, June, 978–996). In this paper a practical approach to heat transfer, heat balance, and burner capacity in industrial furnaces is outlined. Simplified formulæ for computing heat loss, fuel required, and the coefficient of convection in various furnaces are given.—J. A. L.

High-Speed Heating and Forging Expedites Hinge Production. H. Chase. (*Steel*, 1951, **129**, Sept. 10, 96–98). This article describes a slot-type billet heater fed from magazines which deliver billets with one end heated ready for forging into door hinges for Chrysler, De Soto, Dodge, and Plymouth motor cars. One plant described upsets ends on flat blanks at the rate of 1000 units/hr. with two headers.—M. D. J. B.

Some Aspects of Soaking Pit Operation. F. H. Graham. (*Iron Steel Eng.*, 1951, **28**, Oct., 78–84). The fundamental requirements for good soaking pits are considered in detail and waste-heat recovery equipment, automatic controls and the capacity of soaking pits are examined. The relative merits of large 115-ton pits and small 77-ton pits are reviewed in detail and the problems of combustion and heating are also discussed. Methods of obtaining highest production are studied.—M. D. J. B.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat-Treatments in the Works. B. Hedde d'Entremont. (*Rev. Gén. Méc.*, 1951, **35**, Sept., 329–336). The author discusses normalizing, full annealing, hardening, including salt-bath treatment, and tempering.—R. S.

Diffusion in Multiple Phases and Its Metallurgical Application. H. Bückle and J. Descamps. (*Rev. Mét.*, 1951, **48**, Aug., 569–578). The diffusion coefficient in multiple phases is determined for the Al–Be system by a new technique. The method may be applied to the cementation and decarbonizing of steels and the chromizing of iron.—A. G.

Recent Developments in Thermal Treatments with Respect to Heating and Cooling Conditions. A. Sourdillon. (*Rev. Mét.*, 1951, **48**, July, 505–521). The problems of heating rate, time and temperature of soaking, and cooling are discussed. New knowledge of the behaviour of metals under multiple stress, and the generation of stress indicates the advantages of more complex and exactly defined heating and cooling treatments. The field of isothermal transformations extends beyond steels to special cast irons and refractory alloys. Remarkable results have been obtained with some cast irons.

Heat-Treatment of Grey Iron. M. Dobowicki. (*Przeglad Odlewnictwa*, 1951, **1**, Sept., 243–247). [In Polish]. An outline of the heat-treatment of grey iron to remove casting stresses and improve machinability is given.—V. G.

Continuous Heat Treatment Improves Pipe Physical Properties. C. A. Turner, jun. (*Steel*, 1951, **129**, Sept. 17, 97–109). The author describes the continuous heat processing of pipe, both seamless and welded, using high-intensity radiant gas equipment, and discusses the outstanding characteristics of the pipe due to its uniform physical properties and reduced surface oxidation. The advantages of the continuous treatment over the conventional batch treatment are examined and it is shown how the heat-treating cycle can be cut down from 19 hr. to 10 min.—M. D. J. B.

Modern Hardening Methods. E. Knuth-Winterfeldt. (*Dansk Tekn. Tidskr.*, 1951, **75**, Jan., 6–8; Feb., 44–66). [In Danish]. Planning and workshop performance in the quenching, annealing, nitriding, straightening, and hardness testing processes are summarized, and recent methods such as refrigeration hardening, and the use of controlled atmospheres are discussed.—B. S. E.

Electrical Resistance Furnaces in the Modern Heat-Treatment Plant. T. Türk. (*Elektrowärme-Techn.*, 1950, **2**, Aug., 73–79). Modern German electric furnaces employed for heat-treating metal articles, particularly for the tempering of tool steel, for cyaniding and annealing are described.—P. F.

Control Salt Bath when Heat-Treating High-Speed Steel. J. G. Morrison. (*Iron Age*, 1951, **167**, May 31, 63–66; June 7, 110–113). The effects of high temperature (2325° F.) barium chloride salt baths on high-speed steel during heat-treatment are discussed, with particular reference to the analysis, condition, and methods of rectification of the baths. General precautions that should be adopted in using these baths and a simple test for determining whether decarburization or carbon pick-up will occur are given. The thin surface films that form on high-speed steels from commercial atmosphere and salt-bath furnaces have been examined; they should not be confused with the effects of decarburization.

Heat-Treatment Salts. A. L. Simmons. (*Australian Inst. Mét.*: *Australasian Eng.*, 1951, Aug. 7, 44–56). The author presents a logical classification and details of operating procedure for heat-treatment salts in common use. These include nitrate and nitrate-nitrite, chloride, carbonate, and cyanide-containing salts. Impurities and their effects, bath maintenance, pot and electrode materials, general precautions, and typical uses are discussed for each of these types. (45 references).—P. M. C.

An Investigation of the Quenching Characteristics of a Salt Bath. M. J. Sinnett and J. C. Shyne. (*Amer. Soc. Met.*, 1951, Preprint 29). The quenching constant H determining the severity of a quench, is the same for an unagitated salt bath as for an agitated oil bath. Variations are due to surface films. An expression is derived for the value of H in terms of the temperatures of the metal specimen and the bath.

Surface Hardening of Rail Heads. A. Wójcik. (*Hutnik* (Warsaw), 1951, **18**, May, 189–196). [In Polish]. The equipment and costs for surface-hardening rails are discussed, and the "sorbitic" and the Sandberg methods are compared. The factors influencing the depth of the hardened layer, the distribution of hardness over the cross-section of the rail head, and the possibility of heating hardened rails for bending are considered.—V. G.

Fatigue Strength of Large Notched Steel Bars Surface-Hardened by Gas Heating and by Induction Heating. S. L. Case, J. M. Berry and H. J. Grover. (*Amer. Soc. Met.*, 1951, Preprint 26). Surface hardening was found to improve the fatigue strength, and for a particular case-depth the method of heating was found to be unimportant.—E. T. L.

Spoiled Tool Steels Can Be Reclaimed. R. P. Seelig. (*Iron Age*, 1951, **167**, Apr. 12, 97–101). Experiments have been carried out on six tool steels to provide an indication of what may be expected when rehardening and retempering. It is shown that a slightly carburizing atmosphere can be successful in recovering the hardness of tungsten steel and high-carbon, high-chromium steel. The effects of repeated hardening and of reheating to a temperature higher than the first temper have also been studied.—A. M. F.

Cold-Treatment of High-Speed Steel Tools. A. P. Gulyaev, P. P. Grudov and A. A. Badaeva. (*Stanki i Instrument*, 1949, No. 3, 3–6; No. 4, 16–18). [In Russian]. Reasons for the different conclusions on the desirability of using low temperatures to improve the properties of tools are considered. An outline is given of the transformations in steels during quenching in liquid oxygen, and it is concluded that −80° C. is the lowest temperature required in dealing with high-alloy steels and that the cooling must be carried out with the minimum of delay. Experiments on specimens of two high-speed tool steels are described in which the effects of

cold-treatment on phase composition, hardness, and liability to crack formation were determined after various heat-treatments. Operating tests on cold-treated cutting tools are described. The general conclusion is that cold-treatment is most advantageous when close control over quenching conditions is not possible.—S. K.

Low-Temperature Treatment for Hardening High-Speed Steel. W. Haufe. (*Werkstatt u. Betrieb*, 1950, **83**, Apr., 121–125). High-speed steel should be treated to secure the greatest possible transformation of austenite to martensite. This is achieved by repeated tempering, or by a combination of low-temperature treatment and tempering. The author contends that the superiority of low-temperature treatment over correctly carried out tempering treatment has not been established, accept possibly for steels in which the austenite is very stable and which fail to harden sufficiently by tempering. Owing to the long treatment time necessary, considerable cooling capacity must be provided.—H. R. M.

Metallurgical Factors Affect Drill Collar Performance. R. J. Stoup. (Amer. Petroleum Inst.: *Steel*, 1951, **128**, May 14, 90–97). The effects of melting practice, forming and heat-treatment on the performance of drill collars for rotary oil drills are discussed. Seamless pierced collars offer real manufacturing advantages over rolling or forging and attention must be paid in heat-treatment to the prevention of warping and adequate stress relief.—A. M. F.

The Autofrettage Treatment of Gun Barrels. (*Machinery*, 1951, **79**, July 12, 59–61). The autofrettage treatment of 20-pounder gun barrels is described. This is a process of prestressing in which tensile stresses are produced on the outer surface and compressive stresses on the inner by applying a fluid pressure (with glycerine) of 34½ tons/sq. in. on the inside. After releasing the pressure the barrels are heat-treated at 300° C. which relieves the random residual stresses but not the circumferential stresses. Machining operations follow the autofrettage treatment.—R. A. R.

Gaseous Cementation. (*Mét. Constr. Méc.*, 1951, **83**, Sept., 657–663). The fundamentals of gaseous cementation are: (1) The use of a gas which ensures that all chemical reactions take place outside the furnace with the exception of that which supplies the carbon to the steel; (2) avoidance of too much carburizing gas which might cause soot to be deposited; and (3) uniform heating.—R. S.

Study for Applying Material. 4th Report. On the Solid Carburizing Mechanism During A_1–A_3 Points. H. Matsumoto and M. Kitada. (*J. Mech. Lab.*, 1950, **4**, No. 5, pp. 191–195). [In Japanese]. Carburization phenomena are discussed theoretically, using free-energy considerations.

Study for Applying Material. 5th Report. On the Saw-Dust Carburizer. H. Matsumoto and M. Kitada. (*J. Mech. Lab.*, 1950, **4**, No. 6, 236–239). [In Japanese].

Study for Applying Material. 6th Report. On the Mechanism of Grain Refining by the Induction Heating. (Study of High Frequency Induction Heating 2.) H. Matsumoto and K. Yamashita. (*J. Mech. Lab.*, 1950, **4**, No. 6, 240–245). [In Japanese]. The reasons for the production of fine grain by induction heating, how the previous structure influences grain-refining, and which materials are suitable for induction heat-treatment are discussed in connection with the hardening of carbon steels.—T. E. D.

"Zebra" Induction Hardening of Steel Pipes: Metallurgical Considerations in New Treatment of Gob-Stowing Pipes. G. Schulenburg and G. W. Seulen. (*Iron Coal Trades Rev.*, 1951, **163**, Oct. 19, 854–856). Steel pipelines used in the pneumatic filling in of gobs (places from which coal has been extracted) must be sufficiently hard to resist heavy abrasion and also be capable of withstanding shock stresses. A method developed in Germany for hardening such pipes in bands, giving alternate hard and tough sections. The pipes are passed through an electrical inductor and heated in stages, then quenched from the inside by means of a water sprinkler. The equipment is described in detail.—G. F.

Induction-Hardening of High-Speed Tools. L. S. Livshitz. (*Stanki i Instrument*, 1949, No. 7, 27). [In Russian]. A brief account is given of the conditions for the induction heat-treatment of high-speed steel, the microstructure and hardness at each stage being compared with those for ordinary heat-treatment.—S. K.

Ferranti Wild-Barfield Induction Heating Equipment. (*Machinery*, 1951, **79**, Aug. 23, 331–334). Induction heating machines made by Wild-Barfield Electric Furnaces, Ltd., Watford, Herts., are designed for use in conjunction with generators of the valve-oscillator type giving radio frequencies ranging from 250 kilocycles/sec. upwards, and are suitable for the treatment of comparatively small parts and for true surface hardening.—E. C. S.

Economies Obtained with Induction Hardening. R. E. Van Dwenter and G. Bidigere. (*Machinery*, 1951, **79**, Aug. 16, 277–281). Induction heating has been adopted for many selective surface hardening operations by the Packard Motor Car Co. The advantages of this method are the short time required for heating; reduction in distortion; elimination of scale and decarburization; ability to harden specified surfaces; uniformity of degree and pattern of hardness; increased production; and lower costs. A saving of nearly 9*d*. per transmission drive-shaft was effected.—E. C. S.

Induction Hardening and Brazing. R. J. Brown. (*J. Inst. Prod. Eng.*, 1951, **30**, Aug., 436–451). A survey of the practical aspects of induction hardening and brazing is given under the following headings: Operational frequency, generators, hardening by induction heating, steel for skin hardening, brazing materials, transformers and inductors, power requirements, economics, and defects observed.—J. B. B.

Heating by High-Frequency Fields. I. Induction Heating. E. C. Witsenburg. (*Philips Tech. Rev.*, 1949, **11**, Dec., 165–175). After general comments on induction heating, a formula is derived, for a simple case, for determining the efficiency of the work coil through which passes the current that induces the heating current in the workpieces. Various deductions from this formula are shown. Valve generators for induction heating are described, and applications such as surface hardening, annealing, brazing and soldering, and melting are outlined.—J. B. B.

Induction Hardening Tank Turret Bearing Rings. A. H. Allen. (*Steel*, 1951, **129**, July 30, 64–66). This article describes equipment built by the Ohio Crankshaft Co., Cleveland, for hardening the bearing support of tank turrets by electric induction heating at a speed of 0·9 in./sec. or something under 5 min. for a complete ring. Details are given of how it is used and the results obtained.—M. D. J. B.

Nitriding Stainless Steels for Better Wear Resistance. S. Low. (*Steel*, 1951, **129**, Aug. 6, 82–87). The author describes the Malcomizing process developed by the Chapman Valve Manufacturing Co. to overcome the inherent lack of wear resistance of stainless steels. The process uses nascent hydrogen to reduce the thin layer of chromium oxide. The process cycle takes about 40 hr. at 1000° F. in dissociated and ionized ammonia; this is followed by heat-treatment in conventional-type furnaces. The improved fatigue life and general characteristics and applications of nitrided stainless steels are discussed.—M. D. J. B.

The Three Mechanisms of Treatment by Carbonitriding and Quenching. J. Pomey, F. Goutel, A. Veragen, and R. Le Roux. (*Rev. Mét.*, 1951, **48**, Sept., 665–680). An examination is made of the three main cementation processes: (*a*) Cementation in the austenitic state followed by bainitic quenching of the core; (*b*) carbonitriding above the A_c point followed by pearlitic transformation of the core; and (*c*) cementation in the α state. The last two processes apply to all carbon steels not giving martensite on quenching and since only moderate temperatures are employed the risk of overheating and deformation is slight. Hardnesses of 900–1100 Vickers are attainable and the surface is not spoilt by scaling.—A. G.

Wire Annealing Furnace Fits Low Headroom. W. J. Krailing. (*Iron Age*, 1951, **168**, July 12, 93–95). An annealing furnace installation where limited headroom prohibited the use of overhead cranes is described. The furnaces are essentially of the oven type with a gas-fired air heater. The furnaces are charged with pans by a transfer car and unit loads are handled by fork trucks.—A. M. F.

Cyclic Annealing Direct from Forge Operations Produces Outstanding Results at Ford Plant. (*Indust. Heating*, 1951, **18**, May, 790–804). A description is given of a technique of cyclic annealing, utilizing the residual heat in forgings directly from the press. Parts are heat-treated by the salt-bath-furnace isothermal annealing method. Annealing time is reduced to about 45 min. as compared with 5–6 hr. required for annealing in the continuous muffle furnaces previously used.—J. A. L.

An Evaluation of the Hardening Power of Quenching Media for Steel. E. J. Eckel, R. M. Mayfield, G. W. Wensch, and F. A. Rough. (*Illinois Univ., Eng. Exper. Stat. Bull.*, 1951,

Series No. 389, 1–131). This investigation evaluates quenching liquids used in heat-treatment by means of a test that is a modification of the Jominy end-quench test. The authors review standard methods for the evaluation of these media, and examine the effects of quenching in still and in agitated water, brine, oils, and ethylene glycol. Compressed air is also considered.—M. D. J. B.

Hot Oil Quenching Expands Use of Carbon Steels. J. H. Greene. (*Steel*, 1951, **129**, Oct. 1, 64–67). The author describes the quenching of steel in mineral oil at 200–400° F., holding for temperature equalization, and then cooling to ordinary temperatures, usually in air. The advantages and disadvantages of the process are discussed in detail and the author suggests that unless distortion or residual stresses are problems, it may not be desirable to use a hot oil quench, since the process requires more equipment, greater safety precautions, cleaning of the work after quenching, and is limited with respect to size, shape, and type of steel that can be quenched to full hardness.—M. D. J. B.

Tempering of Martensite in Steels. A. Michel. (*Bull. Cercle Etudes Mét.*, 1950, **5**, Sept.–Dec., 337–357). The author makes a preliminary survey of the anomalies observed in the tempering of martensite in hardened high-speed steels and compares some French results with those from other countries.—R. S.

FORGING, STAMPING, DRAWING, AND PRESSING

Hammer Techniques Advance Speed Fabrication of Aircraft Exhaust Systems. (*Steel*, 1951, **129**, Sept. 3, 88–90). A description is given of equipment and manufacturing methods used at Ryan Aeronautical Co., San Diego. It is stated that drop hammers are the only forming method which satisfactorily produce compound curves and sharp radii in the heavy gauges of corrosion-resistant steels used in the aircraft industry. Developments for improved hammer practice, feeder dies, faster positioning in dies, and operation sequences are considered.—M. D. J. B.

Selection of Hammer-Weight for Forging Cutting-Tool Blanks. V. V. Kerekesh. (*Stanki i Instrument*, 1949, No. 7, 25). [In Russian]. Equations for finding the optimum weight of a hammer for forging cutting tools are given, and examples are worked out.—S. K.

Cerium Increases Use of Wrought Stainless. (*Iron Age*, 1951, **167**, June 7, 106). **Forging of High-Alloy Steel Aided by Discovery.** (*Steel Processing*, 1951, **37**, July, 343, 352, 353). Many 'difficult-to-work' high-alloy corrosion and heat-resistant steels can now be made easy to forge and roll by the addition to the melt of 'misch metal,' which contains cerium and lanthanum. This discovery was made in the laboratories of the Carpenter Steel Co. (U.S.A.).—P. M. C.

Forged and Hardened Cold Rolling Cylinders. (*Aciers Fins Spéc. Franç.*, 1951, July, pp. 48–51). A low-chromium hypereutectoid steel (0·85–1% C, 0·2–1·0% Mn, and 1·2–2·0% Cr) is generally used for these cylinders. The initial forging temperature must take into account segregation in the interior of the ingot and in the crystallites, and the fact that this temperature will probably cause the eventual fusion separations and cracks at the limits of the grains to disappear. After cooling, thermal treatments are applied to obtain a fine structure suitable for hardening. Cold-rolling cylinders must normally be drilled to allow cooling during rolling and correct hardening. Hardening provides the final test in which defects are revealed. After hardening and tempering, the cylinders are slightly polished and their hardness is tested.—E. C. S.

Press-Forged Crankshafts . . . Have Continuous Grain Flow. G. S. Cleghorn. (*Machinist*, 1951, **95**, Sept. 22, 1421–1424). The R.R. continuous grain-flow process of forging crankshafts is described.—E. C. S.

Massey High- and Low-speed Forging Presses. (*Machinery*, 1951, **79**, Aug. 23, 322–324). B. and S. Massey Ltd., Manchester, have commmenced production of high- and low-speed forging presses of new design. The high-speed H-type is for use where the 'dwell' of the dies is to be as short as possible to avoid undue loss of heat from the billet. It is available in eight sizes with capacities ranging from 250 to 3000 tons. The low-speed type L is for extrusion since the low speed of the ram reduces the abrasive action of the material on the dies. Four sizes in the 250–1000 ton range with a ram stroke of 8 in. are available.—E. C. S.

How to Work Tool and Die Steels. A. Ashburn. (*Machinist*, 1950, **94**, Nov. 25, 1693–1708). The author deals with the selection and classification of tool and die steels, and how to forge, heat-treat, test, and machine them.—R. A. B.

Increasing Drop Forging Die Life. J. Mueller. (*Steel Processing*, 1950, **36**, Dec., 616–618; 1951, **37**, Jan., 25–27; Feb., 79–81; Mar., 132, 133; May, 235, 236, 250; June, 278, 279, 292; Aug., 389, 390). Part 1 outlines the several standard compositions and degrees of hardness of die block steels. Dies should be uniformly heated before use, should have ample striking surface around the impression, and should be annealed before any rehardening, and strain-relieved after resinking. The choice of draft angles and tolerances is discussed in Part 2, and tables of thickness, shrinkage, die wear, draft angle, and fillet and corner radii tolerances are given. The effects of steel composition on forgeability and die wear are outlined in Part 3. Methods of furnace heating, and the desirability of working at optimum temperature are discussed in Part 4, and the abrasive action of scale is considered. Part 5 deals with the effect of hammer size on die wear and production rates, a chart being shown which enables the hammer size required for a specified area of die impression, weight, and material to be estimated. The occurrence and causes of die shank failure are discussed in Part 6, and Part 7 deals with the use of forging rolls for preliminary shaping—P. M. C.

Press Forging. (*Automobile Eng.*, 1950, **40**, Nov., 363–369). A review is given of the equipment and methods employed by J. Garrington and Sons, Ltd., in the production of forged alloy steel parts for the automobile industry.—J. G. W.

Design of Forging Dies. P. Patek. (*Betrieb u. Fertigung*, 1951, **5**, Apr., 57–60). Rules based on practical experience are given for the design of forging dies. They cover the wall thicknesses between the edges of the forging and the outside of the die block, and the thickness of the block for use either in a hammer or a press; these dimensions depend primarily on the depth of the surface of the forging from the die face. The wall thickness must give sufficient heat capacity and allow for re-cutting of the die after the wear has become excessive.—H. R. M.

Die and Tool Steels for the Drop Forging Industry. H. J. Merchant. (*Metal Treatment and Drop Forg.*, 1951, **18**, Aug., 369–376, 379; Sept., 401–406). The author discusses the requirements, selection, and use of tool and die steels for horizontal upsetting and vertical press forging practice, including roll forging dies, hammer die inserts, trimming presses, and tools for trimming beds and punches.—P. M. C.

How to Approach Shell Forging Problems. K. N. Mills. (*Iron Age*, 1951, **168**, July 5, 90–94). The several forging methods used in the production of artillery shells are described. To solve forging problems a careful analysis of the process must be made bearing in mind the facts that hot metal will always flow in the direction that imposes the minimum resistance to flow, and forging tools follow the line of least resistance.—A. M. F.

Making High Tensile Bolts and Nuts. (*Machinery*, 1951, **79**, Aug. 23, 311–321). The methods employed by A. P. Newall and Co., Ltd., Glasgow, are described.—E. C. S.

Press Brakes and Their Applications. N. C. Wilson. (*Welding Metal Fab.*, 1951, **19**, June, 213–216; Aug., 293–296). The operation of press brakes is discussed. Safety measures are outlined. The applications to forming simple angle bends, special sections, and profiles are illustrated.—U. E.

Speedier Stamping of Axle Housings with Greater Safety. R. E. Hansen. (*Iron Age*, 1951, **167**, June 28, 74–75). Automatic transfer mechanisms and a belt conveyor have been installed in the axle plant of the Oldsmobile Division. Primary aim of these additions is to improve safety in the pressing operations. The main forming press is now kept running continuously with the operator merely loading a magazine with blanks and seeing that the die functions properly. A belt conveyor from this press feeds four secondary presses.—A. M. F.

Modern Cold-Forming Processes. J. Billigmann. (*Werkstatt u. Betrieb*, 1950, **83**, Aug., 345–350; Sept., 394–398). Progress during the last decade in the field of cold forging and pressing is reviewed. The manufacture of various small parts, such as bolts and rivets, balls and rollers, and nuts, is dealt with, and both developments in the processes and improvements in machinery and tools are described.—H. R. M.

Bonderizing as an Aid to the Cold Forming of Steel. H. Kalpers. (*Werkstatt u. Betrieb*, 1950, **83**, Oct., 459–460). Bonderizing, originally introduced for rust-proofing by producing a phosphate coating on steel surfaces, has been found to aid all cold-forming processes in which friction plays a large part. The reduced friction improves tool life and increases the permissible amount and rate of deformation, and surface finish.—H. R. M.

How to Lower the Cost of Prototype Stampings. O. H. Wismer. (*Steel Processing*, 1951, **37**, July, 340–342). The author outlines methods and ideas which enable single prototype stampings to be produced without costly finished dies and tools. Dies built up from wood and plastics are often strong enough to produce just a few parts.—P. M. C.

Estimation of the Stamping Capacity of a Steel by Means of Rational Tensile Curves and the Results of the K. W. I. Test. P. Bastien and C. Winter. (*Rev. Mét.*, 1951, **48**, Sept., 641–658). The modulus of plasticity, $\mu = n/\sigma_r$ (when n is the rational deformation after extension and σ_r the corresponding strain) is difficult to determine with precision and in practice may be replaced by two technical indices (*a*) μ', from the results of the standard tensile test and (*b*) μ'', from the K.W.I. (Kaiser-Wilhelm-Institut für Eisenforschung) stamping test. μ' can be determined accurately for thicknesses above 10 mm. and the spread of results in the K.W.I. test remains constant even for very thin sheets.

Machine Hot-Forms Tubing into Complex Parts. J. Kolb. (*Iron Age*, 1951, **167**, June 28, 78–80). A machine taking tubing up to 10 in. dia. for forming into cylindrical parts and structures is described. Combinations of convergent-divergent sections, graduated diameters, wall thicknesses, and closed ends are obtainable. A section of tubing is held in a hydraulic chuck and, after heating to a white heat by passing a current through it, forming is carried out with a die and/or mandrel. For close tolerance and good finish another machine employs cold forming by rocking dies.

Phosphate Lubricant Aids Cold Extrusion of Steel. (*Iron Age*, 1951, **168**, July 26, 76–77). **New Metal Treating Process Speeds Cold Working, Cold Extrusion of Steel.** (*Mat. Methods*, 1951, **34**, Aug., 68, 69). **Phosphate Lubricating Method to Aid Cold Extrusion, Deep Drawing.** (*Steel Processing*, 1951, **37**, Aug., 391, 413). A brief description is given of a special phosphate coating and organic lubricant combination, which gives a heat-resistant lubricating surface which has exceptional adherence under severe working conditions. The complete process of cleaning, pickling, and application of the coating has been developed by the Pennsylvania Salt Manufacturing Co. (U.S.A.), and is designated the Foscoat Process. Increased production, lower die wear, and higher reductions have been obtained in wire drawing, deep drawing, tube drawing, and cold extrusion.—P. M. C.

Development and Production of Sintered Carbide Drawing Dies. G. Reitzig. (*Werkstatt u. Betrieb*, 1950, **83**, Aug., 361–364). The performance and life of sintered carbide dies depend on production of the correct form of bore and high polish of the surface. The methods of boring, form-grinding, and polishing the bore of the die are described.—H. R. M.

Extruding Hollow-Steel Tapered-Section Propeller Blades. (*Machinery*, 1951, **79**, July 19, 116–117). This new hot-extrusion process was perfected by the Curtiss-Wright Corporation, Caldwell, N.J., U.S.A., in co-operation with the Industrial Planning Division and the Propeller Laboratory, at the U.S. Air Force Development Centre, Adrian, Mich. It has resulted in a new quantity-production method of manufacturing one-piece, hollow-steel propeller blades for high-speed military and commercial aircraft.—E. C. S.

Dies Hardfaced with Alloy Last Longer. A. Gray. (*Iron Age*, 1951, **167**, May 31, 68–70). Descriptions are given of the use to which a nickel base alloy 'Hastelloy C' can be put in hard-facing forging dies. This alloy when deposited has a Brinell hardness of about 210 and can be readily machined; in use it work hardens to 325–375 Brinell and has excellent resistance to chipping and spalling.—A. M. F.

The Reconditioning of Sintered Carbide Dies. Z. Fraczek. (*Hutnik* (Warsaw), 1951, **18**, July–Aug., 299–304). [In Polish]. It is shown that by standardizing the die elements, and correct methods of polishing, the reconditioning of dies can be considerably facilitated.—V. G.

Metal Spinning. D. Reebel. (*Steel*, 1951, **128**, June 4, 88–91; 114). The author considers the potentialities of metal spinning. The metal blank is clamped to a wood or metal form, and revolved in a lathe at from 50 to 2400 r.p.m. Pressure is put on the blank with a long blunt tool, causing the metal to flow closely over the form. Shapes and metals suitable for spinning are examined as well as plate thicknesses. Recently designed automatic spinning lathes capable of handling even 430 and 446 stainless steels, hitherto considered non-formable, are claimed to be very economic.—M. D. J. B.

Methods and Apparatus for Measuring the Profiles of Drawing Dies. W. Lueg. (*Iron Steel Inst., Translation Series*, 1951, No. 428). This is an English translation of a paper which appeared in *Stahl u. Eisen*, 1950, **70**, July 20, 633–640 (*see J. Iron Steel Inst.*, 1951, **168**, May, 101).

Improvement of the Quality of Drawing Dies by Supervision of the Die Profile Using Modern Measuring Methods. W. Lueg. (*Iron Steel Inst., Translation Series*, 1951, No. 429). This is an English translation of a paper which appeared in *Stahl. u. Eisen*, 1951, **71**, Feb. 15, 157–170 (*see J. Iron Steel Inst.*, 1951, **168**, Sept., 63).

Study on a Back Tension Drawing Method. Part II. About the N.N.S. Type Back Tension Drawing Machine. K. Nakamura and O. Nishimura. (*J. Mech. Lab.*, 1950, **4**, No. 3, 118–125). [In Japanese]. A study was made of the relation between angular velocity of the drawing drum and the driving shaft, and the relation between drawing force and back tension force.—T. E. D.

ROLLING-MILL PRACTICE

Calculating the Rolling Force. J. Marczewski. (*Hutnik* (Warsaw), 1951, **18**, May, 186–189). [In Polish]. The formulæ and methods of calculation of rolling force are given.—V. G.

Limiting Maximum Overload on Wound Rotor Induction Motor. J. W. Deimler. (*Iron Steel Eng.*, 1951, **28**, Oct., 90–91). This paper deals with the motor problem involved in the conversion of an 18 × 32 × 56 in. three-high mill to a 28 × 32 × 72 in. mill at the Alan Wood Steel Co. to roll patented floor plates. The author discusses a method of determining the horsepower required to make a given reduction on a sheet of steel and applies the principle to assess the maximum plate length the new mill could roll whilst retaining the 600 h.p., 2300 V., 25-cycle wound rotor motor of the old unit.—M. D. J. B.

Low Inertia D.C. Motors for Rolling Mill Drives. J. H. Schneider. (*Iron Steel Eng.*, 1951, **28**, Oct., 71–76). The author discusses the advantages and disadvantages of low-inertia motors for mill drives. The author concludes that as speeds of mills increase, low-inertia motors gain in importance, increase production, facilitate control, and reduce the demand for power.—M. D. J. B.

Rolling-Mill Operation at Schoeller-Bleckman Stahlwerke A.G., Hoenigsberg-Muerzzuschlag. (*Iron and Coal Trades Rev.*, 1951, **163**, Aug. 24, 423–424). This article describes the Hoenigsberg-Muerzzuschlag rolling-mill plant of the Schoeller-Bleckman Stahlwerke A.G., which produces light sections and alloy steel sheets.—G. F.

Rolling by Water Power. (*Sheet Metal Ind.*, 1951, **28**, Sept., 799, 800). **A Water-Driven Rolling Mill in Daily Operation at Sheffield.** (*Iron Coal Trades Rev.*, 1951, **163**, Oct. 26, 927). A brief description is given of the history of the Starrs Bridge Mill of Eaton and Booth Ltd., which is believed to be the only water-driven steel rolling mill in constant operation in Britain today. The mill still produces about 200 tons per year of rolled flats and squares.—G. F.

Lateral Spread of Metal When Rolling Irregular Shapes. J. Gorecki. (*Hutnik* (Warsaw), 1951, **18**, May, 179–185). [In Polish]. The second pass in the rolling of rails is discussed and formulæ are derived for calculating area displacement and the coefficient of mean elongation.—V. G.

Continuous Operational Control of the Thickness of Rolled Sheets. A. Th. Wuppermann. (*Métaux-Corrosion-Indust.*, 1951, **26**, July–Aug., 306–309). An apparatus is described which indicates within 2% the thickness of a rolled sheet, through its absorption of X-rays as measured by a Geiger counter differential arrangement. The results are independent of temperature, speed, and analysis (within limits) of the steel.—N. McE.

Cold Rolling Strip—An Appraisal of Today's Theory and Practice. J. D. Keller. (*Steel*, 1951, **168**, Feb. 19, 76–82; Mar. 5, 92–96; Mar. 19, 80–86; Mar. 26, 84–89; May 14, 98–104; **129**, July 9, 86–93; July 23, 78–87; Aug. 13, 88–94). The developments in the theory of cold rolling strip

are summarized; the prolems yet unsolved are defined and some minor extensions of the accepted theories are put forward. The 'friction hill' theories are discussed and the author disagrees with Orowan's conclusions that there is a thickening of the sheet as it passes through the neutral zone. This thickening may be due to inaccuracies in roll grinding or in homogeneity of the metal. In cold reducing mills, using large diameter work rolls with good lubrication, the error in calculation of the force on the rolls resulting from the assumption that the deformed roll surface has a circular arc is negligibly small. Observations on the coefficients of friction while in the process of reduction indicate that this will vary along the contact length of the strip, being higher at the exit end than at the entrance end. The effects of rolling speed and lubricants on the coefficient of friction are discussed. It is suggested that a lot more experimentation will be necessary to determine the compressive strength of strip because of conflicting factors. Practical problems in strip mill operation are discussed and remedies suggested. Tests on high-speed cold strip mills emphasize that variations in the speed of rolling affect the thickness of the finished product. This study suggests that the thickness of oil film in back-up roll bearings may exert considerable influence on strip thickness. The author also explains why the rolls become stiffer under high-speed rolling and discusses reasons for end thrust and spalling of rolls and cites the advantages and disadvantages of tungsten carbide rolls.—M. D. J. B.

20 Miles of Pipe per Day. (*Steel*, 1951, **128**, May 28, 78–80). A description is given of a new plant of the Basalt Rock Co. at Napa, California, for the fabrication of 20- to 36-in. steel pipe. Production is up to 1000 tons daily and the tensile strength is increased 12% and yield strength 20% through cold working by passing the pipe through a sizing and straightening machine which shrinks it 1–2%.—A. M. F.

MACHINERY FOR IRON AND STEEL PLANT

What to Look for in Hydraulic Fluids. A. J. Zino, jun. (*Iron Steel Eng.*, 1951, **28**, Sept., 119–125). The application of petroleum oils as hydraulic fluids in industrial equipment is reviewed, and the physical properties essential to oils when used as hydraulic fluids are considered. Specifications are discussed in detail and the effect of temperature on the viscosity–temperature characteristics of hydraulic fluids and the effect of temperature and pressure on overall mechanical efficiency are dealt with.—M. D. J. B.

The Axial Compressor for Blast Furnace Blowing. W. O. Lowell. (*Iron Steel Eng.*, 1951, **28**, Oct., 64–70). A detailed description is given of the technical and operational characteristics of axial compressors and of how these could be used with advantage in the iron and steel industry. The advantages claimed for this type of compressor in blast-furnace blowing are its greater economy, smaller size, very large ratings and higher efficiency through its entire range.

Maintenance of Roller Bearings in Steel Plants. P. L. Haager. (*Iron Steel Eng.*, 1951, **28**, Sept. 9, 172–194). This paper discusses in detail the use and maintenance of mill bearings. After briefly describing the design of tapered roller bearings, and single-row, two-row, and four-row bearings the author describes systems for identification and inspection. The effect of bearing load on life is considered and bearing installation and assembly procedure for mounting bearings on roll necks are described. Lastly the importance of lubrication and the relative merits of different lubricants are dealt with.—M. D. J. B.

Rotary Waggon Tipper—A New Device for Unloading Bulk Products. F. Oltersdorf. (*Stahl u. Eisen*, 1951, **71**, July 19, 749–760). Wagons weighing up to 80 tons and up to 14·2 m. long are mounted in circular end-plates suspended on ropes from an overhead runway, lifted, and rotated 145° about the longitudinal axis using two 400-kW. motors. Coal, ore, and other bulk goods are unloaded in 30 sec. at rates up to 680 t./hr. and at considerably reduced costs. Applications of mobile and stationary tippers in steelworks are described.

A. G.

Maintenance of Metallurgical Equipment in Production Departments. J. Mikulski. (*Hutnik* (Warsaw), 1951, **18**, May, 197–203). [In Polish]. The importance of shortening the time spent on repairs so as to increase output, and achievements in maintenance in the iron and steel industry of the U.S.S.R. are discussed. A maintenance scheme is outlined.—V. G.

LUBRICANTS AND LUBRICATION

Lubrication and Maintenance of Bearings. L. E. Lovitt. (*Iron Steel Eng.*, 1951, **28**, Sept. 9, 169–171). A review is given of the principal types of bearing and how these should be cared for, lubricated and maintained. Especial attention is given to problems arising in anti-friction bearings and the main causes of failure are examined.—M. D. J. B.

For Best Forming Results Use the Right Lubricant. E. L. H. Bastian. (*Steel*, 1951, **168**, May 7, 116–119, 130–133). Water-based fluids, oil-based fluids and solid lubricants are considered for use in press drawing, hot and cold forging, and hot and cold extrusion. Practical tips for the correct selection for use with carbon and low-alloy steels, stainless steel, copper, brass, magnesium, and aluminium are given.

Wax Emulsions Effective as Drawing Lubricants. (*Steel*, 1951, **129**, June 30, 67). Wax blends for use as lubricants in metal-forming operations, such as stamping, wire drawing and cold heading, are finding increasing applications. Judson and Rose, Inc., Philadelphia, are making good use of an aqueous wax emulsion supplied by S. C. Johnson and Son, Inc., Racine, Wis., which is giving good results. The emulsion is applied by dip, spray, sponge, brush, or roller coating.—M. D. J. B.

Laboratory Screening of Multi-Purpose Greases. E. M. Kipp and C. A. Zeiler. (*Iron Steel Eng.*, 1951, **28**, Sept., 107–111). A laboratory method of evaluating greases is outlined and briefly discussed. The results indicate that the laboratory performance tests are of real value in selecting greases which will give more than average satisfaction when used in production. The test schedules are described.—M. D. J. B.

Extreme Pressure Lubricants. J. H. Lewis. (*Iron Steel Eng.*, 1951, **28**, Sept., 114–117). The author discusses the applications of extreme pressure lubricants and the selection of types to be used. The lead–sulphur type of lubricant should be adopted where contamination by moisture is likely. Where there is no moisture, the chlorinated sulphur types are acceptable and cheaper. Details are given of a method of checking the analysis of lubricants. The possibilities of spraying extreme pressure greases by the addition of diluents and solvents are examined.—M. D. J. B.

Maintenance of Oil Film Bearings. S. Carson. (*Iron Steel Eng.*, 1951, **28**, Oct., 106–110). This paper gives a detailed description of oil film bearings and sealing devices as manufactured by the Morgan Construction Co., Worcester, Mass. Lubrication, maintenance, and inspection procedure are discussed.—M. D. J. B.

Lubrication of Wire Rope. J. A. Rigby. (*Iron Steel Eng.*, 1951, **28**, Sept. 9, 131–132). The need for protecting wire rope from corrosion and wear is stressed and the best methods of doing this are described. The properties of lubricants suitable for wire rope lubrication are considered.—M. D. J. B.

WELDING AND FLAME-CUTTING

The Uses and Abuses of Arc Welding Electrodes. I. C. Fitch. (*Trans. Inst. Weld.*, 1951, **14**, Apr., 45–52). Factors affecting the quality of welding are discussed. Special reference is made to the storage of electrodes, workshop conditions, and joint preparation.—U. E.

Adequate Instrumentation Minimizes Welding Variables. J. Heuschkel. (*Steel*, 1951, **129**, July 23, 66–69, 88–90). The author stresses the need for instrumentation in welding so as to analyse and repeat a given set of conditions producing a good weld. The author distinguishes between prewelding instrumentation and process instrumentation and examines the relations between: (1) Welding force, spotweld strength, and consistency; (2) welding time, spotweld strength, and consistency; (3) welding current, spotweld strength, and consistency; and (4) contacting electrode diameter, spotweld strength, and consistency. The instruments used are described. It is claimed that close control of all welding factors results in major savings and guarantees uniformly good welds.—M. D. J. B.

The New Twin-Arc Process. (*Welding Metal Fab.*, 1951, **19**, Aug., 297–300). The development of the twin-arc process is outlined and a description of the equipment given together with electrical and operational data. The process reduces welding time considerably.—U. E.

SIGMA Welding Applications Expand. H. E. Rockefeller. (*Steel*, 1951, **129**, July 16, 75–78). The author describes the 'Sigma (shielded inert-gas metal-arc) process using consumable

electrodes and shows how the method is applied commercially to aluminium, stainless steel, copper, and even to carbon steel. Small amounts of oxygen added to highly purified argon increase welding speed on steel.—M. D. J. B.

Tungsten–Thoria Electrodes for Inert Arc Welding. N. A. Chapin, J. D. Cobine, and C. J. Gallagher. (*Weld. J.*, 1951, **30**, June, 529–531). The use of tungsten–thoria electrodes for inert-gas arc welding was investigated. Great arc stability and a wide operating-current range for a given size of electrode were obtained.—U. E.

Welding and Repairing in Mild Steel. A. H. Barltrop. (*New Zealand Eng.*, 1950, **5**, Sept., 827). Fatigue failures in parts repaired by welding can only be avoided if the metal in the vicinity of the weld is normalized at about 750° C., and if surplus metal which would set up severe stress concentrations is removed.—J. G. W.

Set Up Steel Casting Welding Standards and Procedures. W. D. Wozny. (*Amer. Foundryman*, 1951, **19**, May, 72–79). This paper summarizes the results of extensive research including soundness of weld, composition and physical properties of weld metal, effect of weld and section size and subsequent heat-treatment on the hardness and microstructure of the weld, and effect of welding on the strength of the casting. Three steels were used containing: (1) 0·28% C, 0·75% Mn, and 0·45% Si; (2) 0·29% C, 1·6% Mn, and 0·45% Si; and (3) 0·4% C, 0·75% Mn, and 0·45% Si. Hardness and microstructure are more critical in small welds, especially one-pass welds. Altogether, the results should help in the setting up of standards for welding operations on steel castings.—E. J. D. S.

Resistance Welding of Aluminum Steels and Coated Metals Improved by Slope Control. F. L. Miller. (*Mat. Methods*, 1951, **34**, Aug., 80–82). Slope control involves an electronic attachment to the controls of a resistance welding machine which allows the welding heat to be applied more gradually than normal. This control of the welding current permits successful welds on 'difficult' materials such as aluminium, scaly steel, and stainless steel. Other advantages are longer electrode life, reduced electrode pick-up, and very pronounced increases in production. Several specific applications are described.—P. M. C.

Tantalum Partly Replaces Columbium Control of Electrodes. R. D. Thomas, jun. (*Iron Age*, 1951, **167**, Apr. 5, 109–111). Tests have been carried out to ascertain the effects of varying amounts of tantalum in type 347 weld metal (19/10/1 Cr–Ni–Cb). No significant difference was produced on tensile and stress rupture properties, conducted at both room and elevated temperature, or in resistance to accelerated corrosion or crack sensitivity.—A. M. F.

Pressure Welding. Part I—History. Part II—Cold Pressure Welding. F. C. Kelley. (*Weld. J.*, 1951, **30**, Aug., 728–736). In Part I a brief history is given of the development of pressure welding. In Part II cold pressure welding is discussed. (23 references).—U. E.

The Fabrication and Welding of Austenitic Stainless Steels. P. L. Pocock. (*Sheet Metal Ind.*, 1951, **28**, Oct., 933–942, 944). Immunity from weld decay may be obtained by additions of columbium, or by limiting the carbon content to about 0·05%. After a brief outline of the types of stainless steel which are suitable for welding, the author surveys the precautions necessary at all stages of fabrication in order to avoid blemishes and contamination. Cutting processes are then reviewed, and carbon-arc, gas, argon-arc, and metallic-arc welding techniques are described with particular reference to the avoidance of weld decay.—P. M. C.

Welding Copper-Bearing Stainless Steels. H. Thielsch. (*Weld. J.*, 1951, **30**, July, 341s–347s). The martensitic and ferritic copper-bearing chromium stainless steels are generally welded with standard copper-free 25/12 or 25/20 Cr–Ni electrodes, and austenitic copper-bearing chromium–nickel stainless steels with electrodes of composition similar to that of the base metal. Cracking under unfavourable welding conditions can normally be prevented by careful control of electrode composition and preheating. (20 references).—U. E.

Welding and Its Effect on the Corrosion Resistance of Stainless Steel. E. W. Hopper. (*Weld. J.*, 1951, **30**, June, 503–507). The corrosion of stainless steel welds of types 304 and 316 is discussed. Welded tubing handling paper mill 'white water' with a small concentration of chlorine showed cracking due to corrosion. A sample cut from the shell of a large tubular heat exchanger of type 304 steel showed cracking in the weld area due to corrosion by acetic acid. Water cooling to prevent attack is suggested.—U. E.

Development and Design and Fabrication in Recent British Structures. W. S. Atkins and E. M. Lewis. (*Trans. Inst. Weld.*, 1951, **14**, June, 74–84). New designs for the welding of crane girders and the fabrication of heavy members are described. A strength analysis of rigid frame structures is made.—U. E.

Welded Continuous Frames and their Components. Progress Report 3—Plastic Design and the Deformation of Structures. C. H. Yang, L. S. Beedle, and B. G. Johnston. (*Weld. J.*, 1951, **30**, July, 348s–356s). The plastic behaviour of continuous beams and the deformation of structures in the plastic range is discussed. It is shown that most of the reserve load-carrying capacity of such structures may be utilized without the danger of excessive deformation. A mathematical treatment is given of load-deflection relations.

Continuous Welded Structures, Abbey Works, Port Talbot. W. S. Atkins. (*Trans. Inst. Weld.*, 1951, **14**, Apr., 28–43). Design and welding procedures for crane bearing structures are discussed.—U. E.

Spot Welding of Scaly Heavy-Gage Structural Steel. E. F. Nippes and J. N. Ramsey. (*Weld. J.*, 1951, **30**, July, 327s–336s). Satisfactory spot welding conditions for rust-free scaly structural steel were established for $\frac{3}{16}$- and $\frac{3}{8}$-in. gauges, utilizing a high-pressure low-current preheat and a low-pressure high-current welding sequence. For the as-welded $\frac{3}{8}$-in. material, the normal tensile/shear-strength ratio exceeded the minimum arbitrary limit of 45%. With the $\frac{3}{16}$-in. gauge, it was necessary to temper the welds by passing an additional current, after a proper cooling time, while the metal was still between the jaws of the testing machine if the normal tension/shear-strength ratio was required to be greater than 35%. The strength of welds made in the scaly stock compared quite favourably with the weld strengths of grit-blasted material.—U. E.

Welded Plate Fabrication. P. L. Pocock. (*Welding Metal Fab.*, 1951, **19**, Aug., 278–274). The fabrication of pressure vessels at the works of the Redheugh Iron and Steel Co. (1936), Ltd., Gateshead, is described.—U. E.

Welding on Gas Turbine Engines for Aircraft. H. E. Lardge. (*Trans. Inst. Weld.*, 1951, **14**, June, 85–91). Welding methods for the production of gas-turbine engines are described.—U. E.

Operating Conditions for Carrying Out Keel's Improved Method of Back-Hand Welding. W. Hofmann, H. von Hofe, and W. Newiger. (*Schweissen u. Schneiden*, 1951, **3**, Oct., 297–304). A new process for low-temperature stress-relieving of long welded joints *in situ* as developed by C. G. Keel is described. Directly after back-hand welding the joints they are stress-relieved by passing the flame slowly along them so as to cover three times the width of the weld. Micrographs are given showing the structure of welds subjected to the new treatment in comparison with untreated welds.—U. E.

Oxy-Argon Gas Speeds Up Welding. (*Iron Age*, 1951, **167**, June 14, 85). A new principle said to multiply the speed of inert gas shielded arc welding of stainless steels has been announced by Linde Air Products Co. It has been shown that the droplet rate can be increased as much as 50 times by the addition of small percentages of oxygen to highly purified argon; this allows a higher welding speed or lower current densities.—A. M. F.

Reduction of Residual Welding Stresses by Progressive Heating below 200° C. K. Wellinger and N. Ludwig. (*Schweissen u. Schneiden*, 1951, **3**, Nov., 344–347). Weld stresses are reduced by heating below 200° C. and subsequent cooling. This process of controlled low temperature stress-relieving has been developed in the U.S.A. and is now being applied to welded ships and beams.—U. E.

The Fabrication of Heavy Welded Pressure Vessels. (*Machinery*, 1951, **78**, June 21, 1019–1028; **79**, July 19, 108–112). The methods employed by G. A. Harvey and Co. (London), Ltd., are described. The first part deals with making dished and flanged ends and forming shell plates while the second comprises sections on fusion welding seams, radiographic examination and stress relieving.—E. C. S.

Design and Operation of High-Speed Production Tube Mills. D. H. Fleig. (*Weld. J.*, 1951, **30**, July, 589–596). Various operations performed in a modern resistance welding tube mill are discussed. A complete tube mill producing automatically finished tubing from coiled strip has seven main sections: (1) Uncoiling reel; (2) coil end joining equipment;

(3) tube forming section ; (4) welding unit with its associated electrical control equipment ; (4) weld-bead removing apparatus ; (5) straightening and sizing section ; (6) automatic cut-off equipment ; and (7) tube removal and stacking equipment. These sections are co-ordinated by both electrical and mechanical means.—U. E.

Investigations of the Strength of Gas Welded Rails. H. Kunz and W. Raabe. (*Schweissen u. Schneiden*, 1951, **3**, Sept., 269–272). An investigation on metallurgical properties of gas-welded rails is reported. Heat-treatment is shown to improve the bending fatigue strength considerably.—U. E.

Cold-Cracking in Welded High-Tensile Steels. (*Schweisstechn.*, 1951, **5**, Aug., 88–91). A new weld cracking test, developed in America, is described. A semi-circular groove is filled with weld metal, cooled rapidly in an air stream and examined for cracks. Welding was carried out by the Arcatom, Union-melt, and Argon-arc welding processes. In one case a low hydrogen electrode was used. Cracking was observed with electrodes containing hydrogen. Satisfactory weld deposits showing no cracking were obtained with electrodes containing chromium and vanadium.—U. E.

Stress Concentration Problems in Welded Construction. G. J. Green and D. H. Marlin. (*Weld. J.*, 1951, **30**, July, 607–617). Factors in stress concentration problems are outlined. Examples illustrating the major factors, methods of mitigation and the relative effects are given.—U. E.

Control of Cracking in Arc Welding High Tensile Structural Steels. C. L. M. Cottrell, M. D. Jackson, and J. G. Whitman. (*Welding Res.*, 1951, **5**, Aug., 201r–215r). Prefabricated bridging structures of low-alloy high-tensile steel rolled sections and plates were welded by the A.C. metallic arc process. All relevant data were recorded for each joint. The joints were afterwards sectioned and examined for cracks. The extent to which microcracks spread is shown to bear a relationship to the rate of cooling. A new weldability test has been developed with a range of known thermal severities so that the scope of this work can be extended to cover new electrodes and new steels.—U. E.

Explosion Test Used in Weld Studies. W. S. Pellini and C. E. Hartbower. (*Iron Age*, 1951, **167**, May 30, 83–85).

Explosion Bulge Test Studies of the Deformation of Weldments. C. E. Hartbower and W. S. Pellini. (*Weld. J.*, 1951, **30**, June, 307s–318s). A method has been developed for testing welds in heavy plate under combined stress conditions such as prevail in structures. The test features the bulging of welded plate in diaphragm fashion. Uniform loading of the test plate is accomplished by an air blast set up by the detonation of an explosive. Photogrid deformation studies of prime and butt-welded plates, ¾-in. thick, have been made on spherical and ellipsoidal bulges which provided conditions of balanced (1 to 1) and unbalanced (0·8 to 1) stress fields. The test welds consisted of a firebox steel joined by means of single-pass submerged-arc welds, and also by manual double-V butt welds.—U. E.

Developing a Weldable High Tensile Steel from 18-lb. H.F. Melts. (*Welding Res.*, 1951, **5**, June, 189r–197r). The report discusses the possibility of an 18-lb. H.F. induction furnace welt providing sufficient material for a modification of the Reeve fillet weld cracking test. Low-alloy high-tensile steel (C. 0·15%—Mo 0·25%) was welded with Fastex electrodes. In some cases severe cracking occurred after forging, but the test welds were free from cracks. In general the vertical leg junction zone had slightly lower average hardness than the horizontal, but the tendency to cracking was greater in the vertical leg.—U. E.

Thermit Welding Widely Used in Steel Industry. J. M. Wilson. (*Steel*, 1951, **129**, Sept. 3, 106–109). The author discusses the advantages of Thermit welding and states that while in many cases the process is considered only for repairs, it should be remembered that such repairs are permanent and very often eliminate a weakness in the original casting or forging. Thermit welding of cast iron is also considered. Heat control procedure for stress-relieving is examined and applications of thermit welding are reviewed.—M. D. J. B.

Notes on Weldability, Internal Stresses and Brittle Fractures (in Mild Steel). M. Hansen. (*Dansk Tekn. Tidskr.*, 1951, **75**, May, 155–157 ; July, 203–206). [In Danish]. Standard tests for mild steel are discussed with special reference to the International Welding Conferences of 1949 and 1950.—B. S. E.

Tips on Welding High-Temperature Materials. F. H. Stevenson. (*Iron Age*, 1951, **168**, July 19, 109–111). Brazing and welding techniques employed in the production of precision parts using high-temperature carbon and alloy steels are described. Induction heating is widely used for brazing and the inert-gas-shielded arc process for welding. Precautions for the successful welding of titanium alloys are given. In general, jigs should be designed so that downhand welding can be done.—A. M. F.

Assembly by Brazing. L. Jacobsmeyer. (*Ohio State Welding Engineering Conf. : Metal Ind.*, 1951, **79**, Sept. 14, 215–219 ; Sept. 21, 244, 245). The production of complex parts by furnace brazing several simple components, is usually much more economical than machining the same part from solid stock. Copper brazing procedures are briefly described, and the phenomenon of capillarity between copper and steel is outlined. Many examples of complex copper brazing techniques are given.—P. M. C.

Design Data for Brazing. W. D. Van Natten. (*Weld. J.*, 1951, **30**, May, 452–454 ; June, 540–543 ; July, 634–637 ; Aug., 737–741). Data on design for brazing are given in tables and charts in Part I. The advantages, limitations, compositions, and characteristics of four groups of brazing alloys and fluxes are explained in Part II. Lap and butt joints are illustrated in Part III. Resistance, induction, furnace, torch, and dip methods of brazing are described in Part IV.—U. E.

Cutting Equipment Speeds Steel Mill Scrap Reduction. (*Weld. J.*, 1951, **30**, July, 638–639). The layout of cutting equipment at a steelworks scrap yard is briefly discussed and illustrated.—U. E.

Review of Powder Cutting Processes. R. E. Dore. (*Welding Metal Fab.*, 1951, **19**, Mar., 91–98 ; June, 217–223 ; July, 253–258 ; Aug. 301–307). The following powder cutting methods are described : (1) The flux-injection process ; (2) the iron-rich powder process ; (3) the oxy-kinetic process employs a powder in the form of finely divided silicate but no chemical action occurs between powder and chromium oxides which are removed solely as a result of mechanical abrasion. The metallurgical aspects of powder cutting are studied.—U. E.

Machine-Cutting in the Forge. L. Hodges. (*Trans. Inst. Weld.*, 1951, **14**, Aug., 145–148). Gas profile-cutting machines and processes are described. Forging and cutting procedures are combined in the new designs and examples are shown for the production of spiders, locomotive connecting rods, crankshafts, shear blades, and taper blocks.—U. E.

MACHINING AND MACHINABILITY

A New Method of Machining. J. S. Roller. (*Iron Steel Eng.*, 1951, **28**, Oct., 133–135). The method of metal removal described employs the direct utilization of electrical energy for the machining of any electrically conductive material. The machine removes metal with an electric spark discharge which does not otherwise affect the physical or chemical characteristics of the metal. The machining action depends on a mechanical, not thermal, effect of very high current densities which set up internal mechanical stresses causing metal particles to detach themselves without melting. The process (available through the Method X Corp., Philadelphia) accomplishes such operations as boring, drilling, tapping, and engraving.—M. D. J. B.

Unground Hobs Reduce Gear Tool Cost. F. Bohle. (*Iron Age*, 1951, **167**, June 7, 107–109). The application of unground hobs to the cutting of gear teeth is described. They are less expensive and have a longer life than ground hobs and are more economical in high-production jobs where the tool cost is a substantial part of the total cost. The tolerances for accurate unground hobs, adopted by the American Metal Cutting Tool Institute, are tabulated.—A. M. F.

Use of a Pneumatic Method of Evaluating the Quality of Surface Finish. M. L. Brzhezinskii. (*Stanki i Instrument.* 1949, No. 3, 20–22). [In Russian]. In the instrument described and illustrated, the profilograph needle is mechanically drawn over the surface being investigated and its vertical movement causes changes in the size of the aperture through which air leaves a flow system. The changes in air pressure are registered on a recording manometer whose drum is rotated by the same motor as that which moves the specimen.—S. K.

Acid Pickle Doubles Tool Life on CI. J. Datsko. (*Machinist*, 1951, **95**, July 7, 1002–1003). Research at the University of Michigan shows that the interior of a sand casting can be

machined with high-speed-steel tools 88% faster than the surface. Pickling in hydrofluoric acid increases surface machinability 80%, and lengthens tool life 45 times.—E. C. S.

Superior Machinability of MX Explained.—F. W. Boulger, H. A. Moorhead, and T. M. Garvey. (*Iron Age*, 1951, **167**, May 17, 90–95). Statistical studies have been made to explain the variations in machinability among Bessemer free-cutting steels. It is shown that small variations of silicon content, even within the normal range, have a marked influence. For B-1111 steel the machinability rating decreased one-third as the silicon increased from 0·005 to 0·025%. The effects of sulphur, phosphorus, and carbon, and of inclusions are discussed.—A. M. F.

Carbide Drills Increase Tool Life on Cast Iron. E. J. Weller, E. J. Bonesteel, and F. W. Lucht. (*Iron Age*, 1951, **167**, May 31, 75–79). Extensive tests have been carried out to secure data on the thrust, vibration, torque, horsepower, and drill reconditioning when drilling cast iron. Four types of drill are compared. Carbide drills gave from three to ten times the tool life and about twice the production rate of high-speed steel drills.—A. M. F.

CLEANING AND PICKLING

Pickling Accelerators. G. Rossi-Landi. (*Mét. Constr. Méc.*, 1951, **83**, Sept., 687–689). Accelerators can be used at the beginning of pickling. They activate the acid attack to uncover the metal. The inhibitor functions as a protector by preventing the evolution of hydrogen and reducing the formation of ferric salts. The accelerator is again used when the bath is saturated with salts and when the final acid is no longer active.—R. S.

Forgings Descaled 90 per Cent Cheaper. (*Steel*, 1951, **129**, Aug. 13, 80–81). This article describes a new method, developed by the Pennsylvania Salt Manufacturing Co., of removing furnace scale from steel forgings. A bath is made up of a patented product dissolved in weak HCl and water which completely removes scale during quenching. It is claimed that in one plant, this process effects a saving of 90% compared with previous methods.—M. D. J. B.

A Universal Bath for Electrolytic Polishing and Metal Removal. J. E. Battle. (*Galvano*, 1951, **20**, Feb., 11–13). A solution has been developed in which all metals can be successfully electropolished. Its composition is: Sulphuric acid 25, hydrofluoric acid 33, boric acid 8·3, chromic acid 372, citric acid 12, phthalic anhydride 4·3, and phosphoric acid 328 g. per litre. It is used at 94° C. with copper or stainless steel cathodes, anodic current densities varying from 5 to 70 amp./sq. dm. depending on the metal being polished. If the current is passed after attainment of the full degree of polish, there is no change in smoothness but metal is removed at a uniform rate. It is thus possible to carry out, in one operation, polishing and reduction of size of oversized articles. The bath has a very long life and requires only infrequent attention.—J. P.

Hydrogen Embrittlement of Plated S.A.E. 1060 Steel. (*Products Finishing*, 1951, **15**, June, 22–68). Samples of S.A.E. 1060 steel, which had been heated, oil-quenched, and tempered to 45–47 Rockwell C, exhibited embrittlement when pickled in HCl but recovered 99% of their bending ability after 10 hr. storage at room temperature or for shorter periods at higher temperatures. Samples of this steel were plated with cadmium after having been pickled or cleaned by tumbling. Although they were all embrittled, the samples tumbled or stored for some time after pickling before plating recovered their bendability in the same way as pickled steel, but those plated shortly after pickling were still quite brittle after 24 hr. at room temperature. Care should be taken to segregate free-cutting steel during pickling, since it is possible that amounts of sulphur, selenium, or phosphorus may otherwise enter the pickling solution and promote embrittlement of any steel subsequently pickled.—J. P.

Hydrogen Embrittlement in Steel on Electroplating. U. Trägårdh. (*IVA*, 1949, **20**, 5, 193–217). [In Swedish]. In this investigation of the hydrogen absorption of three carbon steels during treatment preceding plating the embrittlement has been determined by two bending-test methods. Hg^{++}, CN^- and SCN^- ions increase the embrittlement when pickling cathodically in alkaline baths, whilst Sb^{++} and Te^{++} have similar effect on cathodic pickling in H_2SO_4. Anodic pickling in 10% H_2SO_4 gives very low embrittlement in hydrogen-sensitive steels, and is recommended.—B. S. E.

Investigation of the Efficiency of Inhibitors for the Economic Pickling of Steel. (*Hutnik* (Warsaw), 1951, **18**, July–Aug., *Biuletyn Informacyjny, Glownego Inst. Met.*, 25–27). [In Polish]. A description of an apparatus for the determination of the velocity of hydrogen evolution during pickling of steel is given. When testing inhibitors, not only the velocity of hydrogen evolution must be considered, but also the diffusion of hydrogen into the specimen. For this reason a factor H_N for the percentage of brittleness inhibition is introduced. After 2 to 3 hr. pickling, the specimen is washed and repeatedly bent until broken. $H_N = 100N/N_0$, where N_0 and N are the number of bends to cause fracture before and after treatment respectively.—V. G.

Halides as Acid Pickling Inhibitors. K. F. Hager and M. Rosenthal. (*Corrosion*, 1950, **6**, Oct., 344–346). The results of experiments to determine the effect of halogens and halides on the acid attack on mild steel are reported. Inhibition of acid attack was found to increase with the increase of the atomic weight of the halogen used, iodine and iodides being effective inhibitors in concentrations greater than 0·1%, bromine and bromides, and chlorine and chlorides being also effective (in that order), but fluorine and fluorides acting as accelerators. Tests were made in pickling solutions of 1 and 5 *N* H_2SO_4 5% HNO_3 using various temperatures, inhibitor concentrations, and test durations—O. H. G.

Metal Cleaning in Aqueous Media. P. D. Liddiard. (*Metal Ind.*, 1951, **79**, July 27, 63, 64; Aug. 3, 91–93; Aug. 10, 107–109; Aug. 17, 123–127; Aug. 24, 151–153). Part 1 discusses the available methods (chemical, physical, mechanical). The series only covers physical methods of the type generally referred to as alkali degreasing or cleaning. Part 2 introduces the idea of residue adhesion strengths, and contact angles, surface tension, and the degrees of wetting and spreading are discussed. Elementary theory is given which enables the work needed to overcome adhesive forces of liquids like oil to be calculated. Part 3 examines the forces operating when two liquids (say, oil and a detergent) are competing for a solid surface. For initial action, a high interfacial tension between the competing liquids is probably more desirable than a low one. Part 4 outlines the functions and operation of an ideal detergent. A list of surface-active compounds is given, with recommendations on their uses. Part 5 discusses the all-important aspect of agitation in detergent processes. (20 references).—P. M. C.

PROTECTIVE COATINGS

Low-Cost Equipment Improves Electroplating. G. W. Jernstedt. (*Iron Age*, 1951, **168**, July 26, 73–75). Simple techniques for improving general electroplating practice are given. These include the use of spray rinses, fog nozzles, diaphragms, air agitation, filtration, heat exchangers, and periodic reverse plating processes. These methods when used to the best advantage can produce big benefits at low cost and with the minimum of alteration to existing plant.—A. M. F.

Study of Electrolytic Deposition from Very Dilute Solution. Parts I and II. A. Coche. (*J. Chim. Phys.*, 1951, **48**, Mar.–Apr., 135–145; 146–149). When radio-elements are used as tracers in electrolytic depositions, they are used in very dilute solution. In connection with this, work is reported on the following aspects: (*a*) Influence of concentration of radio-elements on the critical potential. (*b*) Influence of the nature of the electrode on the critical potential. Polonium, lead, and bismuth are deposited on a variety of metals including molybdenum, tungsten, tantalum, gold, and platinum. The potentiostat, an apparatus for maintaining an electrode at constant potential, is described.—T. E. D.

Recent Developments in Low Voltage Electrical Supply. (*Galvano*, 1951, **20**, Feb., 15, 16; Mar., 15–17; Apr., 17–19). The development and characteristics of copper oxide and selenium rectifiers for electroplating are described. The following features to be considered when installing rectifiers are discussed: The most economic conditions for their application; the methods used to dissipate the heat generated therein; connecting in parallel for heavy currents; control; and protection against overload. In order to comply with present specifications for electrodeposits, automatic control of plating vats is now being adopted. Plating at constant voltage, constant current, and constant current density are dealt with.—J. P.

Temperature and Heating in Electroplating Processes. H. W. Dettner. (*Metalloberfläche*, 1950, **B**, **2**, Dec., B181–

B182). Maintenance of the temperature within given limits is imperative for the prevention of faults in the metal deposits, particularly those which arise in cold baths. Temperatures and conditions suitable for nickel, chromium, copper, brass, and gold plating are given. Electrical bath-heaters of different types are described and illustrated.—P. F.

Solution Heating Methods Improve Plating Plant Operating Efficiency. A. Q. Smith. (*Products Finishing*, 1951, **15**, July, 58–62). The use of gas-fired and electric immersion heaters has aided the production of uniformly high quality plated ware by maintaining constancy of electrolyte temperature.—J. P.

The Formation of Spots on Galvanic Deposits. W. Burkart. (*Metalloberfläche*, 1950, B, **2**, Sept., B134–B135). Spots on galvanic deposits, indicating flaking off, are associated with incomplete degreasing, with oxide films formed where excessive heat developed during polishing before electrodeposition; and with sulphur contamination from sulphur-bearing polishing pastes. Tests for sulphur in the pastes, based on discoloring polished copper plates on to which the paste is applied, are mentioned, and a simple method for the determination of the *p*H values of pastes is described. Neutral pastes are best.—P. F.

Porosity of Galvanic Deposits. R. Erdmann. (*Metalloberfläche*, 1950, B, **2**, Sept., B138–B140). The various types of porosity of surfaces encountered in electroplating are discussed and their origins are traced. Mention is made of the use of detergents in the electrolyte to reduce surface tension and facilitate escape of gas bubbles, chiefly hydrogen. The use of oxidants such as hydrogen peroxide and potassium permanganate in the bath is dealt with, together with other methods effective in combating porosity.—P. F.

Comparative Testing of Metal Coatings. G. C. Close. (*Products Finishing*, 1951, **15**, Aug., 20–22). A very brief description is given of a method in which dry air is used to agitate test solutions in contact with coated test panels contained in glass jars.—J. P.

PROPERTIES AND TESTS

Chemistry and Technology of Metals and Alloys. (*Nature*, 1951, **168**, Sept. 8, 414–415). A review is given of papers presented to the joint meetings of the Chemistry and Engineering Sections of the British Association on August 14, 1951. These were "Chemistry in Metal Extraction" by F. D. Richardson; "The Strength of Metals" by A. H. Cottrell; "A Survey of Alloy Development over the Past Ten Years" by A. G. Quarrel; and "Brittle Fracture in Mild Steel" by T. S. Robertson.—A. G.

Low-Cost Testing Machine Has Electronic Indicating System. (*Product Engineering*, 1951, **22**, July, 118–119). Brief descriptions are given of new universal testing machines, which cost about half as much as standard equipment of similar type. The machines have capacities ranging from 1200 to 400,000 lb. with a 50–1 spread of testing ranges. The indicating system is electronic and entirely separate from the hydraulic loading system, thus making it possible to change the test ranges during a test without altering the rate of loading.—M. D. J. B.

The Tensile Test. P. Laurent. (*Bull. Cercle Etudes Mét.*, 1950, **5**, Sept.–Dec., 358–375). The author reviews the following: Stress/strain curves; the theories of Ludwik and Gensamer and of Voce and McCance; effect of cold work on the elastic limit; effect of complex stresses on ductility; distribution of stresses in a notched specimen; the mechanisms of rupture in single crystals and in a polycrystalline structure; and relationships between elongation and reduction in area.

The Mathematics of the Tensile Test. H. Kostron. (*Arch. Eisenhüttenw.*, 1951, **22**, Sept.–Oct., 317–325). The true stress/strain curve of metals can be represented with sufficient accuracy by a parabola $\sigma = a.d^n$ in the range between the 0·2% proof stress and the ultimate tensile stress. The tensile strength, the proof stress, and proof strain are expressed in terms involving the extension corresponding to the ultimate tensile stress and the strength and work-hardening parameters a and n of the true stress/strain curve. Deviations between the values thus determined and those obtained experimentally were found in certain cases. Such discrepancies are important in shaping processes for metals, and their further study is recommended.—P. F.

Delayed Yield in Annealed Steels of Very Low Carbon and Nitrogen Content. D. S. Wood and D. S. Clark. (*Amer. Soc. Met.*, 1951, *Preprint* 23). Investigations on low-carbon steel with subsequent removal of differing amounts of carbon show that reducing the carbon and nitrogen contents lowers the stress level of the delay-time/stress relation. Delayed yielding occurs in a steel previously wet-hydrogen-treated to remove the static upper yield point. The absence of an upper yield point is due to a change in the relative magnitudes of upper and lower static yield points, not to a fundamental change in the mechanism of yielding.—E. T. L.

The Determination of Flow Stress from a Tensile Specimen. E. R. Marshall and M. C. Shaw. (*Amer. Soc. Met.*, 1951, *Preprint* 24). Experiments on copper and steel have been carried out to test Bridgman's ideas on the connection between the true stress/strain relationship and the radius of the neck profile. The results are in quantitative agreement, though they do not support another theory connecting true strain with a flow stress correction factor. The need for a suitable tensile flow stress correction factor is illustrated by the case of the cutting of metals.—E. T. L.

How to Determine Toughness of Steels from Notched Bar Tests. E. J. Ripling. (*Mat. Methods*, 1951, **34**, Sept., 81–85). The author shows how notched properties (tensile strength, ductility, impact energy), when plotted as a function of the normal tensile strength (varied by heat-treatment), can be used to indicate safe and unsafe strength levels. The graphs also enable comparisons to be made between the toughness properties of different steels at the same hardness.—P. M. C.

Work-Hardening of Mild Steel by Explosive Attack. J. S. Rinehart. (*J. App. Phys.*, 1951, **22**, Aug., 1086–1087). The attenuation of a high intensity compressive stress wave generated in a steel plate by application of an explosive charge permitted work-hardening observations to be made at various stress levels. The data show that the change in hardness varies in a characteristic manner with the distance the wave has travelled. A number of general conclusions can be drawn as to how the change in hardness produced by the stress wave is influenced by the residual hardness of the parent material. A typical work-hardening curve for annealed 0·20° C. steel plate is given.—J. P. S.

Temperature and Stress Rate Affect Fractology of Ferritic Steels. C. A. Zapffe and C. O. Warden. (*Iron Age*, 1951, **167**, June 28, 65–69). This report gives details of a study of the fracturing of types 430 (17% Cr) and 446 (26% Cr) ferritic stainless steels over a temperature range from 22° to 475° C. and under the fracture conditions of (*a*) a hammer blow, and (*b*) a rifle shot. Temperature and velocity of fracture were found to be counteracting factors. Under hammer blow these steels showed transition to slip-type patterns at between 35° and 100° C. Fracture by rifle shot produced identical patterns at a temperature 150° C. higher.—A. M. F.

Reversion to Brittleness on Reheating. L. D. Jaffé and D. C. Buffum. (*Rev. Mét.*, 1951, **48**, Aug., 609–612). Samples from steel SAE 3140 were given various heat-treatments and their Charpy impact values determined. Brittleness is rapidly reduced by reheating to a higher temperature than that causing fragility, but reappears gradually after prolonged soaking at these temperatures. This brittleness develops by a process of nucleation growth and is not due to the segregation of dissolved elements.—A. G.

Improved Tests Evaluate Nodular Iron. W. W. Austin. (*Iron Age*, 1951, **167**, Apr. 19, 86–89). Mechanical properties of nodular iron obtained from keel block tensile specimens can be misleading and should be appraised judiciously. Because of the section sensitivity of nodular iron, test specimens are needed which are closely representative of the actual casting and the following recommendations are made: For sections $\frac{3}{4}$ in. and under, the standard A.S.T.M. 0·625-in. dia. malleable test bar; due to decreased section sensitivity in the range above $\frac{3}{4}$ in., and up to 2 in., the keel block may be used; for all castings having section thickness 2 in. or over standard tensile specimens should be machined from a heavy section specimen having a cross-sectional area approximately equivalent to the average of the casting.—A. M. F.

Investigations into the Impact Strength of Iron and Steel. J. D. Fast. (*Philips Tech. Rev.*, 1950, **11**, Apr., 303–310). The Charpy notched-bar impact test is described and the theories of the stress distribution in a loaded metal and its relation to the possible occurrence of either plastic deformation or brittle fracture are discussed. It is suggested that

brittle fracture occurs when the cleavage strength is exceeded before the shear strength is reached under an increasing load. This is more likely to happen in impact than in the normal tensile test. The results are given of impact energy measurements made on pure iron and on iron containing traces of impurities. Oxygen (0·015%) reduces the impact value at 20° C. to one-fifth of that of pure iron ; this effect is greatly diminished by traces of carbon.—J. G. W.

Effect of the Direction of Deformation on the Notched Bar Impact Strength of Artificially Aged Specimens. E. Uhlir. (*Betrieb u. Fertigung*, 1951, **5**, May, 77–80). Notched bar impact tests were carried out on a 0·2% C steel containing 0·05% Al, artificially aged by a 10 per cent. cold deformation followed by ½ hr. at 250° C. When the deformation was carried out by tension or compression in the rolling direction, the impact-strength/temperature curve fell steeply below 0° C., but when the deformation was by compression in either of the two directions perpendicular to rolling, this critical temperature was raised to 20° C. The tendency to ageing, as shown by the fall in the notched bar strength after ageing, was 11% at room temperature, 61% at 0° C., and 65% at −10° C., for deformation perpendicular to the rolling direction. If ageing tendency is specified at temperatures below 20° C., the direction of deformation must be considered.

Reactions Produced by Working and Reheating in 18/8 Low Carbon Steels. P. Bastien and J. Dedieu. (*Génie Civil*, 1950, **127**, Dec. 15, 469–471). Stainless steels (18/8) exist in two forms, stable and unstable. The former hardens less on working than the latter. Methods of studying the effect of stress on the structure of these by cold drawing, X-ray diffraction, and a magnetic technique are outlined. The changes brought about during reheating after working are also given.—T. E. D.

A Defect in the Present Theory of Elasticity. O. Föppl. (*Schweiz. Arch., angew. Wiss Techn.*, 1951, **12**, June, 171–177). A complicated stress condition can always be split up into the sum of (*a*) a hydrostatic stress (three equal principal stresses) and (*b*) a stress condition in which the sum of the three principal stresses is always zero. If a body is so stressed that the hydrostatic stress is the same at all points while only the stresses comprising (*b*) depend on the position in the body, the principal strains are easily calculated. In the case of bending, both the components (*a*) and (*b*) depend on the position in the body, and in this case the usual assumption made when working out the principal strains, namely, that the strain components due to the hydrostatic stress are equal in the three directions, is not valid.—H. R. M.

Mechanical Deformation of Metals. C. Chaussin. (*Mét. Constr. Méc.*, 1951, **83**, Sept., 665–671). The author describes the deformation of single crystals, slip, shear, twinning, and the plasticity of polycrystalline structures.—R. S.

Deformation Textures in Face-Centred Cubic Metals. E. A. Calnan and C. J. B. Clews. (*Phil. Mag.*, 1950, **41**, Nov., 1085–1099). Previous attempts to explain the deformation behaviour of polycrystalline aggregates in terms of the slip mechanisms, operative when single crystals are deformed, are discussed. From the qualitative treatment of the authors it is possible to derive : (1) A tensile-stress/elongation curve which is in satisfactory agreement with experiment and with that previously observed by Taylor ; and (2) tension, compression, rolling, and wire-drawing textures which are in reasonable agreement with observation. An attempt is made to give a clearer physical basis for the deformation process. A tentative explanation for the variation of deformation textures among metals of the same crystal structure is offered.—J. P. S.

On Combined Bending and Twisting of Thin Tubes in the Plastic Range. R. Hill and M. P. L. Siebel. (*Phil. Mag.*, 1951, **42**, July, 722–733). Equations for the determination of the stresses and warping in a partly plastic thin tube of arbitrary section are obtained for any monotonic loading by bending and twisting couples. The analysis is based on the von Mises yield criterion and the Reuss stress/strain relations. The equations are solved numerically for a circular tube for various loading programmes.—J. P. S.

The Moving Griffith Crack. Elizabeth H. Yoffe. (*Phil. Mag.*, 1951, **42**, July, 739–750). The stress field is calculated about a straight crack moving through an elastic medium. The stresses depend on the velocity and reduce to Inglis' solution when the velocity is zero.—J. P. S.

The Use of Plasticine Models to Simulate the Plastic Flow of Metals. A. P. Green. (*Phil. Mag.*, 1951, **42**, Apr., 365–373). The behaviour of plasticine when permanently deformed is compared with that of an ideal metal, and the necessary conditions for similarity between their flow patterns are examined for flow in two and in three dimensions. A brief account of the mechanical properties of plasticine includes a description of stress/strain curves obtained by compressing cylinders between lubricated plates at constant rates of loading. Plane strain experiments with plasticine marked with a grid on a cross-section parallel to the plane of flow are described and photographs of the deformed grids are compared with theory. The processes examined were : (1) Extrusion through square and wedge-shaped dies ; (2) indentation of a plane surface by a single wedge and by a row of wedges ; and (3) compression of a narrow wedge by a flat die.—J. P. S.

An Experimental Investigation of Plastic Stress-Strain Relations. J. L. M. Morrison and W. M. Shepherd. (*Proc. Inst. Mech. Eng., App. Mech.*, 1950, **163**, W.E.P. 55, 1–9). The authors describe tests carried out on a 5% Ni steel and on an Al/11% Si alloy. The investigation discriminated between the 'incremental' and 'total' strain types of plastic strain theory in the region where the plastic and elastic strains are of comparable magnitude. Thin tubular specimens were subjected to successive increments of tensile and torsional stress in a new combined-stress testing machine : no appreciable unloading took place. Three-dimensional diagrams are shown of the dependence of strain on the axial and torsional stresses. In these the measured strains are compared with the strains predicted by the 'total' theory and also by a form of 'incremental' theory previously described by Shepherd. It is concluded that the 'incremental' strain type of theory is the more correct.—J. G. W.

A Mechanism for the Growth of Deformation Twins in Crystals. A. H. Cottrell and B. A. Bilby. (*Phil. Mag.*, 1951, **42**, June, 573–581). By extending the recent theory of slip bands, proposed by Frank and Read, it is possible to show that a dislocation can move steadily from plane to plane in a crystal. A theory of mechanical twinning which is formally analagous to Frank's theory of crystal growth can then be developed. The theory is applied to the body-centred and face-centred cubic lattices.—J. P. S.

Theoretical Study of the Plasticity of Crystals. P. Laurent. (*Métaux-Corrosion-Indust.*, 1951, **26**, July–Aug., 292–305). The author illustrates the type of dislocation found in crystals, calculates the forces and energy associated with them, and discusses their mobility, stability, and origin. For their stability, Mott's theory, that the irregularities themselves maintain their own stability is in contrast to that of Kochendörfer and others, which stresses that the energy of the system is less than that for a homogeneous crystal stretched to the same dimensions. The Bragg theory, the dislocation, and the Laurent theories of the formation of dislocations are then considered, first for two- and then for three-dimensional systems, and finally with reference to (*a*) the influence of temperature on shearing strength, (*b*) the curve of consolidation, (*c*) creep in single crystals, and (*d*) the plasticity of solid solutions.—N. McE.

Factors of Stress Concentration for the Bending Case of Fillets in Flat Bars and Shafts with Central Enlarged Section. J. B. Hartman and M. M. Leven. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, 53–62). Using Fosterite and the stress-freezing photoelastic technique, factors of stress concentration have been determined for the case of a flat bar, containing a central enlarged section and connected by a fillet, when subjected to pure bending.—P. M. C.

Ring-Method Determination of Residual Stresses. K. P. Milbradt. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, 63–74). The ring method of residual stress determination involves placing wire resistance strain gauges in a scribed ring, and then machining a hole and an isolating ring with a circular cutter about the gauges. The method is analysed mathematically, and some experimental results quoted. (19 references).—P. M. C.

Some Unorthodox Procedures in Photoelasticity. A. J. Durelli and R. L. Lake. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, pp. 97–122). Photoelastic polariscope designs are discussed, and a large-field diffused light type of instrument is described and its performance outlined. Simplified techniques, which do not require the time and skill of conventional

methods, are discussed, and the creep properties of phenol-formaldehyde plastics are described. The use of the creep phenomenon for freezing stresses without the conventional heating is outlined. (10 references).—P. M. C.

Characteristics of Wire Gages under Various Conditions. H. Majors, jun. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, 123–139). An experimental programme is described and reported, in which the variation of gauge sensitivity from −310° F. to +140° F. was determined for wire gauges types A-3 and A-15 mounted on steel and constantan beams respectively. In addition, types AB-14 and A-15 were mounted on small blocks of aluminium, brass, and steel in order to observe the variation of indicated strain with temperature while the compensating gauges, mounted on a brass block, were held at room temperature. (59 references).

Characteristics of Electric Strain Gages at Elevated Temperatures. E. E. Day. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, 141–150). Gauge factors have been determined for 21 standard type SR-4 gauges at temperatures from room up to 200° F., or to the highest temperature of response without a critical break in performance. The gauges were cemented to an iso-elastic beam, and the beam deflections were measured by means of a Tuckerman optical strain gauge. The results indicate that each gauge is an individual and cannot be classed in characteristics by any type or number by which it is now known.—P. M. C.

An Optical Strain Gage for Use at Elevated Temperatures. P. R. Weaver. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, 159–162). An optical strain gauge, employing a double mirror arrangement in conjunction with an auto-collimated projected and observing system, is briefly described. The mirrors (one fixed, and the other rotated by the specimen movement), are made of Stellite, and the gauge operates satisfactorily up to 500° F. Fused quartz, coated with silicon or rutile, is being developed for mirrors to be used at 1000° F. and over.—P. M. C.

Development and Use of High-Temperature Strain Gages. R. E. Gorton. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, 163–176). The author describes in detail the methods used to make special gauges for attachment to turbine rotor blades which operate at temperatures up to 1500° F. The gauges are made from 0·0007-in. Nichrome V wire, and are bonded to the test surface with a specially developed mixture of high heat-resisting paint and a ceramic coating.—P. M. C.

Resistance Wire Strain Gages in Product Development. W. H. Buckley and R. G. Anderson. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, 177–190). This paper presents some applications of Baldwin SR-4 resistance wire strain gauges in product development engineering. Their stability and the effects of moisture, time, and temperature are discussed.

A Wire Resistance Strain Gage for the Measurement of Static Strains at Temperatures up to 1600° F. J. E. Carpenter and L. D. Morris. (*Proc. Soc. Exper. Stress Anal.*, 1951, **9**, 1, 191–200). The techniques and apparatus used in fabricating and instrumenting the Cornell strain gauge are described, and its properties and some test results obtained with it are given. The wire used is 0·001-in. Nichrome V, and the cements used are Quigley Triple A1920 paint, and Sauereisen No. 1 cement.—P. M. C.

A More Realistic Measure of Shot Peening Effectiveness. C. Lipson. (*Steel*, 1951, **129**, Aug. 6, 72–75). The author describes the remarkable advantages of shot peening in improving the life of highly stressed machine parts. The strengthening is caused by compressive stresses set up in the surface layer and by changed shape and orientation of the crystalline grains. The author suggests that fatigue strength, not fatigue life, is the more logical yardstick to determine improvement in performance of surface treated parts subject to fluctuating loads. (17 references).—M. D. J. B.

Study for Applying Material. On the Mechanism of Tensile Failure of the Inductively Hardened Steel. H. Matsumoto and K. Kimura. (*J. Mech. Lab.*, 1950, **4**, No. 5, 196–200). [In Japanese]. A previously derived extension of Woodvine's fatigue theory for case-hardened steel was found to be applicable to inductively hardened steel. The change of characteristics due to tempering was studied in the case of two steels, and results are given.—T. E. D.

On the Fatigue Strength and Damping Capacity of Time Piece Spring. T. Mitsuhashi and K. Tsuya. (*J. Mech. Lab.*, 1950, **4**, No. 5, 180–185). [In Japanese]. The damping capacity of oil-quenched and tempered springs is lowest at the tempering temperature 300–400° C. When the spring is tempered at constant temperature, damping capacity rapidly decreases, then slowly increases with tempering time. Experimental results on austempering were irregular.—T. E. D.

METALLOGRAPHY

Twenty-Five More Years of Metallography. J. R. Vilella. (*Amer. Inst. Min. Met. Eng.*, 1951, Aug., 605–619; *J. Met.*, 1951, **3**, Aug.). The author appraises the achievements which have contributed most to the progress of microscopical metallography during the past 25 years.—G. F.

Recent Developments in Metallography. E. C. W. Perryman. (*Metal Ind.*, 1951, **79**, July 13, 23–26; July 20, 51–53; July 27, 71–73; Aug. 10, 111–113; Aug. 17, 131–133). Taper sectioning techniques which magnify differences in surface contour, the use of special Bakelite cements for mounting specimens without the application of heat or pressure, and mechanical and electrolytic polishing techniques, are briefly described. The phase-contrast microscope, the reflecting microscope, which is achromatic and has a long working distance, and the application of polarized light to the examination of grain structures, preferred orientation, oxide coatings, internal strains, plastic deformation, and non-metallic inclusions are dealt with. Multiple-beam interferometry for the examination of surface topography, and the advantages of the electron microscope are both briefly discussed. Finally, the Brit. Non-Ferrous Metals Res. Assoc. microhardness tester is described. (41 references).—P. M. C.

The Place of the Metallurgist in Production Engineering. E. R. Gadd. (*J. Inst. Prod. Eng.*, 1951, **30**, Apr., 208–218). The duties of the metallographer and production metallurgist who act in an advisory and inspectional capacity in a modern engineering works are discussed. Their importance in the development of cast iron, aluminium alloys, electrical processes, and nitrogen hardening is outlined.—J. B. B.

The Principals and Uses of Absorption Microradiography in the Investigation of Metals and Alloys. Z. Bojarski. (*Hutnik*, (Warsaw), 1951, **18**, May, 212–215). [In Polish].—V. G.

On the Examination of Metal Surfaces Using Lacquer Replicas and the Phase-Contrast Technique. W. Faasch, G. Hein, and L. Koch. (*Metalloberfläche*, 1950, A, **4**, Sept., A129–A135). Lacquer replicas of metal surfaces, of the type employed in electron microscopy, were examined by transmitted light in the phase-contrast microscope. Micrographs of electrolytic zinc deposits, copper plating, and etched aluminium surfaces were taken and compared with similar micrographs obtained by direct observation in the ordinary microscope by reflected light. Comparison shows the phase-contrast and lacquer technique to be superior. Details of the method are discussed.—P. F.

Grain Shapes and Other Metallurgical Applications of Topology. C. S. Smith. (*Amer. Soc. Met. Preprint* 37, 1951). The similarity of the shapes of soap bubbles, biological cells, and metal grains is shown to spring from a simple arithmetical criterion, and the disappearance of soap bubbles in a vessel of constant volume is considered as analogous to grain growth, and suggests that the latter is due to surface tension forces. Consequently recrystallization is understood as the migration of the relatively high-energy surfaces of large bubbles. The criterion also shows that, for a given number of cells, the minimum interface energy is obtained when five-edged interfaces predominate, as is found in practice.—E. T. L.

Austenitic Grain-Size Control of Steel. B. R. Nijhawan and A. B. Chatterjea. (*Met. Res. Comm., Council Sci. Indust. Res.*, New Delhi, 1951, 1–58). Work on controlled inherent grain size of steels is fully reviewed. The different methods of revealing austenitic grain size in steels of various compositions made by different processes are studied and compared with the standard McQuaid-Ehn test. The physical properties of commercial tyre and axle steels of Indian and foreign origin are examined and correlated with their austenitic grain size. The McQuaid-Ehn grain size is not influenced by previous heat-treatment or severe mechanical working at high temperatures. Controlled grain-size steels can be made by judicious additions of aluminium. Experimental mild steel, axle, tyre, Cr–Mo, and Ni–Cr steels with controlled grain size were made, chemically analysed, forged, and heat-treated. These steels had higher impact toughness, determined by the Izod test, slightly higher ductility, and lower hardenability than commercial steels of similar composition and heat-treatment.

Stability of Hexagonal Lattices Submitted to a Simple Stress System. F. R. N. Nabarro and J. H. O. Varley. (*Rev. Mét.*, 1951, **48**, Sept., 681–683). A study was made to decide if the effect of Brillouin zones and the polarization of ions would be to deform an originally close-packed lattice or whether lattices with c/a ratios other than 1·63299 can exist even in the absence of these effects. Conditions of equilibrium and stability, the free electron gas, and examples of structures with central forces and Fermi energy are discussed.—A. G.

Effect of Prior Treatment on Precipitation of Sigma Phase. G. V. Smith, E. J. Dulis, H. S. Link. (*Weld. J.*, 1951, **30**, Aug., 385s–396s). An investigation on the effect of heating in the range 1700–2300° F. after cold deformation and the formation of sigma phase in 18/8 and 25/20 stainless steels during subsequent exposure at 1300° F. for up to 7500 hr. is reported. Both steels recrystallized on heating at 1700° F. or higher. Neither the quantity nor distribution of sigma changed significantly with cooling rate from 1700° F. but for the 1900° F. level slower cooling yielded slightly more sigma. No sigma was observed in 18/8 (Nb-stabilized) steels. Both steels developed sigma if exposed at 1300° F. The maximum amount in 25/20 steel was estimated to be 30–40%, and considerably less in 18/8 steel (5–10%). A variation in cooling rate after previous treatment at 1700° or 1900° F. had little effect on precipitation of sigma at 1300° F. in 25/20 steel, but after previous treatment at 2100° or 2300° F., the amount of sigma for any time at 1300° F. decreased directly with decrease in cooling rate.—U. E.

CORROSION

Corrosion of Metals. G. T. Peat. (*J. Inst. Prod. Eng.*, 1951, **30**, Feb., 55–61). Corrosion is defined; forms such as galvanic action, differential aeration, graphitic wastage, and caustic embrittlement are described, and the usual preventive measures used in steam boiler practice given. The use of coatings is touched upon.—J. B. B.

Some Fundamentals of Corrosion and Protection. M. A. Comley. (*Indust. Finishing*, 1951, **3**, July, 976–980). The author discusses aspects of corrosion from the electrochemical point of view and deals with cathodic and anodic control of corrosion. Methods of protection are also considered.—E. T. T.

Corrosion Processes and Their Prevention. W. H. J. Vernon. (Royal Inst. Chem.: *Indust. Finishing*, 1951, **3**, July, 993–994). It is pointed out that corrosion presents a field of the utmost attraction for study and research. The discussion of the paper is reported.—R. A. R.

Experiences from the Study of Corrosion Problems in U.S.A. P.-Å. Wallgren. (*IVA*, 1950, **21**, 1, 35–41). [In Swedish]. An evaluation is made of various anti-corrosive measures as recorded by the Amer. Nat. Assoc. Corrosion Eng. The purity of the zinc coatings is of special importance for the protection of iron submerged in water. (28 references).—B. S. E.

Report on Round Table Discussion on General Corrosion Problems. F. L. LaQue. (*Corrosion*, 1950, **6**, Oct., 327–331). This is a discussion, in question and answer form, of general corrosion problems.—O. H. G.

Some Applications of Electrochemical Thermodynamics. M. Pourbaix. (Assoc. Italiana di Metallurgi: *Corrosion*, 1950, **6**, Dec., 395–403). The affinity and velocity of electrochemical reactions, the magnitude and sign of which can be measured, are discussed, taking into account all the electrochemical processes that can take place on the same metallic surface. It is shown that such study is facilitated by a knowledge of the polarization curves. The treatment is applied to the behaviour of iron in the presence of aqueous solutions.—O. H. G.

The Significance of the Activity of Metal Surfaces in Electrochemical Reactions. K. Wickert. (*Metalloberfläche*, 1950, A, **4**, Dec., A181–A186). According to U. R. Evans the well-oxygenated electrode in a corrosion cell should be the more corrosion resistant. It is shown that this is so only for polished electrodes. In the case of electrodes of iron and other metals it was found that the activity of the surfaces played a decisive part in corrosion, and in highly active worked surfaces the principles enunciated by U. R. Evans are inapplicable as they do not take surface activity into account. The nature of the local, microscopic, corrosion couples is discussed, and evidence for a type of couple not so far considered in corrosion experiments, is adduced. In these couples direct electron transfer takes place.—P. F.

A New Method for the Protection of Metals Against Pitting, Tuberculation and General Corrosion. H. L. Kahler and C. George. (*Corrosion*, 1950, **6**, Oct., 331–340). Corrosion experiments in a continuous-flow water system using a new method of corrosion inhibition (the 'dianodic method') are described. It comprises the use together of two anodic inhibitors, phosphate and chromate, at concentrations at which either inhibitor acting alone would be ineffective. Quantitative corrosion-pit data are presented on specially prepared steel specimens accompanied by data on tuberculation on the threads of pipe nipples. It is claimed that pit reductions of 80–90% are not unusual from this new method, and that the combination loses none of its effectiveness in controlling the general corrosion of metals, being equal to protection by chromate alone and far superior to phosphate treatment at controlled pH. Plant results in recirculating cooling water systems so far indicate complete accord with the experimental data presented.—O. H. G.

How to Avoid Galvanic Corrosion. (*Steel*, 1951, **128**, May 21, 82–83, 104–110). The process of electrochemical corrosion is described and it is emphasized that for protection electrical insulation must be provided. Insulation washers or gaskets, paint or plastic sealing compounds may readily be used. In certain cases plating may be helpful, or a sacrificial piece of a third metal can be added at the joint.

Some Methods of Protection Against Metallic Corrosion. T. A. Evans. (*J. Inst. Prod. Eng.*, 1951, **30**, Feb., 62–78). The importance in metallic corrosion of anodic corrosion, differential aeration, porosity of metals and the atmosphere is outlined. The following aspects of protection against atmospheric corrosion are given: temporary protection, protection by paints and their binding medium, preparation of surface before painting, application of paints and breakdown of films.—J. B. B.

An Investigation of the Longevity of Galvanized Roofing Sheets and Wires. D. J. Swaine. (*Chem. and Indust.*, 1951, Sept. 15, 764–767). A chemical study of some old and new specimens of the above materials has indicated that the greater coating weight on the old ones was the only reason for their greater longevity.—N. McE.

Corrosion of Welded 18/8 Type Chromium–Nickel Steels in Concentrated Nitric Acid. H. T. Shirley and C. E. Nicholson. (*J. Iron Steel Inst.*, 1952, **170**, Feb., 111–118). [This issue].

A Method of Selecting Protective Coatings for Offshore Drilling Structures. J. P. Barrett. (*Corrosion*, 1950, **6**, Nov. 376–383). A method of laboratory testing organic protective coatings intended for marine operations associated with petroleum production is described. A moisture vapour transmission salt-spray and adhesion test was used and correlation between the laboratory and the marine test station exposure is given as 91%.—O. H. G.

Selection of Protective Coatings for Chemical Fume Resistance. C. C. Harvey. (*Corrosion*, 1950, **6**, Oct., 323–326). Nearly 300 selected proprietary coatings were tested for chemical fume resistance first by accelerated laboratory tests in hydrochloric acid and in chlorine fume cabinets to screen out unsatisfactory materials, and then in field tests at two sites, one to test weathering properties and the other fume resistance. Carbon black, titanium dioxide, chromic oxide, toluene red, phthalocyanine green, phthalocyanine blue, and hausa yellow were the most satisfactory finish coat pigments tested.—O. H. G.

Study of Wear Phenomenon of Steel against Soil. (1st Report). T. Mitsuhashi, Y. Imai, and S. Yokoi. (*J. Mech. Lab.*, 1950, **4**, No. 3, 91–96). [In Japanese]. Preliminary results were obtained for dry and damp sand, using a new testing machine.—T. E. D.

Some Aspects of the Corrosion of Iron in Earth and Its Prevention. P. Nycander and G. Nilson. (*IVA*, 1947, **18**, 1, 28–30). [In Swedish]. The underground parts of steel pylons are stated to be effectively protected against corrosion by two layers of red lead and one top coating of bituminous paint. Since the painting is very time-consuming, zinc coating is usually preferable, except in acidic soils.—B. S. E.

Corrosion in Water and Its Prevention. E. Palmaer. (*IVA*, 1948, **19**, 4, 163–183). [In Swedish]. British, American, and French reports on the corrosion of iron and steel, protected and unprotected, in water, are reviewed. (23 references).—R. A. R.

Reactivated Warships Prove that "Mothballing" Worked. C. H. Sigel. (*Iron Age*, 1951, **167**, May 24, 85–89). This article details methods used in the preservation of the

American Reserve Fleet. Maintenance of a humidity of less than 30% is essential to prevent moisture-induced corrosion, mould, and mildew, and this is an essential part of the programme.—A. M. F.

The Use of Cathodic Protection in Conjunction with Paint Coatings. W. L. Crosby. (*Corrosion*, 1950, **6**, Nov., 383–388). This is a Progress Report on an investigation by the consolidated Edison Co. of New York, Inc., to devise means of controlling the corrosion of the steel transformer bodies installed in manholes where they are subject to complete or partial immersion in salt water at high tide. The laboratory tests used to select the paint scheme (three coats of an asphalt base paint) are described. Tests to discover the feasibility of using cathodic protection in conjunction with the protective coating are in their initial stages, and have so far involved (1) choice of a suitable electrode (magnesium); and (2) investigation of (*a*) effect of cathodic currents from magnesium electrodes on four different paint coatings; (*b*) effect of electrolytes containing various mixtures of salt and fresh waters; (*c*) effect of the magnitude of the cathodic current; and (*d*) actual field installation of a magnesium electrode in a tidal transformer manhole.—O. H. G.

Design of Anode Systems for Cathodic Protection of Underground and Water-Submerged Metallic Structures. E. R. Shepard and H. J. Graeser, jun. (*Corrosion*, 1950, **6**, Nov., 360–375). A brief analysis of the potential gradient in the medium between the anode and the cathode for protected underground metallic structures is presented. The resistance R of a hemisphere to remote ground is deduced to be $R = \rho/2\pi a$, where ρ = the specific resistivity of the medium and a = radius of hemisphere; that of a vertical rod to ground $R = 0{\cdot}0324\ \rho/L$ (ρ in ohms/cm., L length of rod in feet; L must be large compared with the diameter). Calculated resistances obtained with the second equation are compared with those obtained using Dwight's and Peter's equations as well as with measured values using an A.C. bridge. The resistance to remote ground of a limited length of horizontal pipe is considered.—O. H. G.

A Study of Some Metals for Use as Permanent Anodes in Water-Tank Cathodic Protection Systems. A. L. Kimmel. (*Corrosion*, 1950, **6**, Nov., 353–359). The paper presents corrosion data on a number of commercial non-ferrous metals and alloys, and stainless steels used as permanent anodes. Investigations were made in water of *p*H 6·3 and 8·6, using current densities of 0·25 to 4 amp./sq. ft. It is concluded that: (1) 18/8 stainless steel is the most suitable metal; and (2) on the basis of weight, aluminium is the most inexpensive metal, even though it does require more frequent replacement.—O. H. G.

Control of Corrosion by Salt Used for De-Icing Highways. J. A. Temmerman and A. Sterlin. (*Corrosion*, 1950, **6**, Dec., 391–394). Laboratory tests of a polyphosphate nitrite base inhibitor developed to control corrosion by salt brines is reported. Results (quoted as weight loss of mild-steel panels as a function of inhibitor and salt concentrations) show the inhibitor to be effective. Experience in the use of the inhibitor incorporated in rock salt by the City of Rochester, N.Y., U.S.A., is discussed.—O. H. G.

Surface Potential Method of Corrosion Survey of Pipelines. O. W. Wade. (*Corrosion*, 1950, **6**, Oct., 341–343). This is a review of the surface potential methods for corrosion surveys on pipelines.—O. H. G.

Weathering Tests of Tin-Zinc Alloy Coatings on Steel. S. C. Britton and R. M. Angles. (*Metallurgia*, 1951, **44**, Oct., 185–191). Information is presented on the behaviour of electrodeposited tin–zinc alloy coatings in weathering tests in urban, suburban, and marine atmospheres. In urban and suburban atmospheres the protection afforded by coatings of equal thickness diminished in the order zinc, 50/50 Sn–Zn alloy, 80/20 Sn–Zn alloy, cadmium. By the sea, an alloy with 50% Sn was rather better than zinc or cadmium. In tests involving more continuously humid conditions, Sn–Zn alloy was superior to zinc.—J. B. B.

Corrosion Properties of Automobile Gear Oils. A. Bukowiecki. (*Schweiz. Arch., angew. Wiss. Techn.*, 1951, **17**, June, 182–191). The possibility of additives in extreme pressure gear oils causing corrosive attack, chiefly on the gear tooth surfaces, has been studied. The oils tested, heated to 80–120° C. even after a prolonged contact, only slightly attacked iron. With chlorinated oils there was a distinct tendency to after-rusting. The higher the temperature to which the oil is exposed the more severe is the after-rusting.—H. R. M.

Caustic Cracking: Stress-Corrosion Tests in Sodium Hydroxide Solutions at Elevated Temperatures. C. D. Weir. (*Proc. Inst. Mech. Eng., Appl. Mech.*, 1950, **163**, W.E.P. 55, 18–23). Stress-corrosion investigations at temperatures of about 250° C. were made on hollow mild-steel specimens. Intercrystalline failures, similar to those that occur in practice, could be produced consistently in specimens having a circumferential **V**-notch; unnotched specimens were immune. Concentrated NaOH is more effective in causing failure than dilute solutions. Pure solutions are as effective as the commercial quality. The presence of tannin does not prevent cracking, nor does the use of a fine-grained steel unless carbon content is also slightly increased.—J. G. W.

ANALYSIS

Identification of 3 Stainless Alloys Simplified. A. W. Smolla. (*Iron Age*, 1951, **167**, June 21, 97–98). Simple qualitative chemical tests for identifying types 316, 321, and 347 stainless steel are given.—A. M. F.

Analyzing Stabilized Stainless Now Takes Less Time. J. F. Young. (*Iron Age*, 1951, **168**, July 12, 91–92). A method for determining tantalum-plus-niobium in stainless steel is described. These two elements are separated as pentoxides and the tantalum/niobium ratio is determined spectrographically. The niobium is determined concurrently with the other elements present spectrochemically. This method is claimed to be faster as the time taken by the wet chemical method is halved.—A. M. F.

Colorimetric Determination of Metals in Industrial Wastes. P. G. Butts, A. R. Gahler and M. G. Mellon. (*Metal Finishing*, 1951, **49**, Apr., 50–60, 63). Most methods now recommended for water analysis are subject to serious interference by even moderate concentrations of other cations and anions; several metals are often present in a single sample of polluted water. This paper presents colorimetric methods for each of the metals, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc. The methods are designed to allow the determination of as little as 0·05 mg. (0·05 p.p.m.) of the ion in question in a one litre sample, and are applicable in the presence of the other heavy metals listed up to at least 200 times the concentration of the desired constituent. Allowance is also made for the presence of organic matter, and such anions as may be commonly found in polluted water.—J. P.

Colorimetric Aluminium Determination in Titanium-Bearing Steels. J. Carroll, I. Geld, and G. Norwitz. (*Amer. Foundryman*, 1951, **19**, June, 57). The method previously described by the authors (*see J. Iron Steel Inst.*, 1951, **167**, Jan., 109) was found to be of no use for steels or high-temperature alloys containing titanium, since the titanium hydrolysed out when the colour was developed. After several attempts to solve the difficulty a method was developed in which the cupferron filtrate was evaporated to a volume of about 2 ml. before developing the colour. Details of this final procedure are given.—E. J. D. S.

Colorimetric Determination of Iron, Manganese, Phosphates and Silica. W. Teichert. (*IVA*, 1946, **17**, 4, 135–152). [In Swedish]. Iron in amounts less than 0·01% is accurately determined in an amyl-alcohol/amyl-acetate extract of the coloured ferric thiocyanate; a colorimetric method suggested for phosphates is based on the reduction of phospho-molybdic acid complex by a photographic developer (Rodinal). A new colorimetric method for the determination of manganese consists essentially in obtaining permanganate by oxidation and measuring the intensity of the blue colour resulting with potassium iodide and starch.—B. S. E.

Determination of Boron in Steels. Margaret W. Kelly. (*Anal. Chem.*, 1951, **23**, Sept., 1335–1336). The boron in the sample is converted to boric acid by treatment with HCl and H_2O_2. Anhydrous calcium chloride is added and methyl borate is distilled off by passing methyl alcohol vapour through the hot mixture. After evaporation of the distillate to dryness in the presence of excess sodium hydroxide, the residue is dissolved in hydrochloric acid and the boric acid content determined by titration with standard sodium hydroxide in the presence of mannite.—J. B. B.

Direct Reading Spectrograph is Faster, More Accurate. B. J. Tufty. (*Iron Age*, 1951, **167**, June 7, 104–105). The laboratory of the Compagnie Radio-Cinema in Paris, France,

have developed a spectograph for the direct reading of spectrum lines of alloys. The apparatus includes a head unit with electron multiplier photoelectric cells to replace the usual photographic chassis.—A. M. F.

Absorption Spectrophotometry. H. Arnfeldt. (*Jernkontorets Ann.*, 1951, **135**, 2, 45–74). [In Swedish]. The principles of absorption spectrophotometry are broadly outlined with special reference to the different sources of error.—B. S. E.

An Application of Geiger Counter Tubes for Spectrochemical Analysis. O. G. Koppius. (*Philips Tech. Rev.*, 1950, **11**, Jan., 215–220). An instrument is described for the detection of atmospheric contamination with lead compounds caused by small leaks in industrial plant. The apparatus is suitable for the detection of other elements.—J. G. W.

Segregates in Steel Analysed Spectrographically. (*Steel*, 1951, **129**, July 9, 78–80). The use of spectographic methods for the study of segregates in steel is described. Local and traversing spark techniques are discussed. With the latter, segregates are examined by traversing the samples with a highly localized condensed spark (1 mm./min.) while the photographic plate on which the spectrum is recorded moves downward across the camera aperture of the spectrograph.

Spectrophotometric Determination of Silicon. H. Arnfeldt, S. Freyschuss and B. Rönnholm. (*Jernkontorets Ann.*, 1951, **135**, 2, 75–86). [In Swedish]. The authors give a literature survey of the subject and describes silicon determinations in steel by the technique suggested by U. T. Hill (*see J. Iron Steel Inst.*, 1949, **163**, Dec., 478).—B. S. E.

Apparatus for Determining Hydrogen in Steel. K. Amberg and S. Kämpinge. (*Jernkontorets Ann.*, 1951, **135**, 5, 177–185). [In Swedish]. A simple modification of Newell's apparatus for determining hydrogen in steel by extraction at 700° C. is described.—B. S. E.

A Method of Determining Hydrogen in Steels. F. Meunier and A. Demarez. (*Rev. Mét.*, 1951, **48**, Aug., 598–608). Details of a vacuum extraction method for determining hydrogen in solid steels are given. For ordinary steels the error is of the order of 0·1 c.c./100 g. The application of the method to studies of (*a*) the influence of moisture in electrode sheaths on the hydrogen in weld metal, and (*b*) the hydrogen in certain ferro-alloys, is described and its extension to the hydrogen content of liquid steels considered.—A. G.

A Semi-Micro Gas Analyser. L. Moreau and P. Albert. (*Rev. Mét.*, 1951, **48**, Sept., 684–686). The apparatus having negligible dead space, and using mercury as a liquid mover is described together with the operating technique. It is simple and robust, and in good conditions the analysis of gases for hydrogen, carbon monoxide, and nitrogen, on volumes of 0·5 to 5 c.c. can be carried out.—A. G.

A Method for Determination of Tar, Soot and Water in Producer Gas. B. Lundén and K. N. Cederquist. (*Jernkontorets Ann.*, 1951, **135**, 5, 186–193). [In Swedish]. In this analysing procedure for producer gas a mixture of methylene chloride and methyl alcohol is recommended as absorbent for the tar.—B. S. E.

Photometric Determination of Potassium in Mixed Fertilizers from Open-Hearth Slags and Potassium Salts. E. Piper and H. Hagedorn. (*Arch. Eisenhüttenw.*, 1951, **22**, Sept.–Oct., 299–301). A rapid spectrographic method for the estimation of potassium in fertilizers containing powdered open-hearth slags is described. Up to 48% of potassium can be determined in 5 min. with an accuracy sufficient for the control of the composition within commercially stipulated limits.—P. F.

HISTORICAL

The First English Blast-Furnace. H. R. Schubert. (*J. Iron Steel Inst.*, 1952, **170**, Feb., 108–110). [This issue].

MISCELLANEOUS

Ventilation of Steel Mill Buildings. W. S. Johnson. (*Iron Steel Eng.*, 1951, **28**, Sept. 9, 145–149). After considering how little was done in the past to ensure adequate ventilation of steel-mill buildings, the author maintains that far too little is done even today. The ineffectiveness of many present ventilating systems are examined and suggestions for improving conditions are put forward.—M. D. J. B.

Heating of Steel Mill Buildings. G. J. Campbell. (*Iron Steel Eng.*, 1951, **28**, Sept. 9, 139–143). The author stresses the need for analysis of all factors affecting comfort when considering a heating problem, since discomfort may not be due to temperature alone but to other factors such as draughts. Types of heating and ventilating equipment are described; methods of control, maintenance procedures and safety measures are examined.—M. D. J. B.

Lighting of Steel Mill Buildings. D. H. Tuck. (*Iron Steel Eng.*, 1951, **28**, Sept. 9, 133–137). The author considers the latest types of incandescent and fluorescent lamps.—M. D. J. B.

Problems in Steel Plant Administration. H. W. Johnson. (*Iron Steel Eng.*, 1951, **28**, Oct., 122–126). The author discusses the problems of administration, organizational development and training of personnel in steelworks.

The Elimination of Defects in Metallurgical Plant. J. S. Caswell. (*Swansea Met. Soc.*, 1951–52, 1–32). The general requirements for eliminating plant breakdown are summarized under the headings: (1) Plant manufacture and erection; (2) plant operation; and (3) works control. Particular attention is given to good design and correct loading, and the theory is briefly outlined. Experimental methods of stress analysis are described, and these include the photo-elastic method, the electric resistance strain gauge and the brittle lacquer method.—T. E. D.

Some Metallurgical Aspects of Engineering. J. M. Robertson. (*Bull. Inst. Met.*, 1951, **3**, May, 4–24). Having first defined in general terms, metallurgy and engineering, the author discusses the relations between them in industry and technology. Properties and specifications of metal products are next dealt with. The differences in the relations between metallurgy and engineering under conditions of normal production and when changes are being made are pointed out.—J. A. L.

Radioactive Materials in Industrial Metallurgy. Sheila M. Holgate. (*Metallurgia*, 1951, **44**, Oct., 179–184). A brief general discussion of radioactivity is followed by more detailed consideration of its use in metallurgical research, chemical analysis, production control, and as a source of power.—J. B. B.

Flow of Gases in Porous Media. L. H. Wilson, W. L. Sibbitt, and M. Jakob. (*J. Appl. Phys.*, 1951, **22**, Aug., 1027–1030). This paper presents a brief theoretical review of the viscous and free molecular flow phenomena. The equations which describe these two types of flow are applied to flow through porous media and are combined to yield a semi-empirical equation which may be used for these two types of flow and for the transition region between these. Experimentally determined limiting values of the ratio of molecular mean free path to pore diameter are reported. These ratios may be used to indicate the nature of flow in a porous media provided the pore size is known, or they may be used to determine pore size experimentally.—J. P. S.

The Production of Tonnage Oxygen in a Large Industry. L. Dupaty. (*Rev. Tech. Luxembourg.*, 1951, **43**, July–Sept., 126–130). A description of the classical Linde and Claude cycles and their limitations is given and the development of regenerators in the period 1930–1945 is traced. The demand for cheap oxygen by the metallurgical industries has led to intensive studies to improve operational efficiency. The recent application of the double and "oxytonne" cycles are described.—B. J. B.

BOOK NOTICES

British Iron and Steel Research Association. "*The Instrumentation of Open-Hearth Furnaces.*" 8vo, pp. xiv + 159. Illustrated. London, 1951: George Allen and Unwin, Ltd. (Price 30*s.*)

In an earlier review I commented on the advent of a new publisher to metallurgy and here we have another book issued by George Allen and Unwin, Ltd., again in the form of a report from the British Iron and Steel Research Association. As in the previous book, the production is of a high order and in particular in this volume the numerous line drawings are large and clear and leave nothing to the imagination. The book is designed to give a modern, general account of the principles of open-hearth furnace instruments and their application in British steel plants.

The book is primarily intended for melting-shop managers and their staffs, but it is suggested that it will also be useful to those engaged in instrument maintenance. In addition, it provides a succinct account for anyone interested, and, for example, should prove useful for the teacher wishing to obtain an up-to-date outline without working through the numerous papers on the subject. It is stated that, because of rapid developments in instrumentation, new editions will be issued frequently.

Interest is immediately stimulated by Sir Charles Goodeve's pithy foreword. Only a few days ago I tried without much success to convince a rather stolid metallurgical trainee of the value of pyrometers in open-hearth steelmaking compared with reliance on more empirical methods. After I had shown him Sir Charles's foreword and other parts of the book he changed his views. In particular, Sir Charles's story of the hardening-shop goldfish, appealed to him more even than the testimony quoted later from Mr. F. L. Robinson, the first chairman of the Open-Hearth Instruments Sub-Committee. Mr. Robinson testified that he had made steel for many years without instruments and for many years with instruments, and in spite of the difficulties mentioned he gives his unqualified advice to all young melters to use measurements and, when possible, automatic regulation.

It is perhaps difficult for those not engaged in an industry, such as steelmaking, which has evolved over the years without known scientific principles and control, to appreciate the general resistance and the psychological barrier to the introduction of instruments. The 'human' difficulties are clearly demonstrated by a remark made to me by a member of the laboratory staff of a large steelworks engaged in introducing pyrometers. He said, "If in the first year, we can just get the men willing to look at the instruments and accept their presence, we shall be satisfied." I think it is agreed that such difficulties are more pronounced in that part of the industry making large tonnages of steel than in the more specialized side of the trade.

The present volume does not deal with this aspect of instrumentation, attention being confined to technical matters. The book is divided into two parts. In the first, the broad function and principles of the instruments are described. In Chapter 7, entitled, "The Function of Instruments," the case for instrumentation is presented. It is pointed out that furnace trials have shown "that heat transfer is controlled by so many factors that there is little hope of maintaining optimum operating conditions other than by the use of instruments." The factors to be taken into account in instrumentation are discussed and the benefits emphasized. Several specific examples of the benefits obtained by well-known concerns are described. Chapter 2 consists of just over three pages stating the essential measurements that must be made. In the next chapter the principles of pressure gauges, flow-meters and pyrometers, and of the operation of these instruments are described in straightforward language, illustrated with virtually self-explanatory diagrams. I have not seen clearer diagrams anywhere. There then follows in Chapter 4 instructions on the "Use of Instrument Readings." "Instrument Panel Layout and Location" are described in Chapter 5, whilst the concluding chapter deals with "Automatic Control." As the latter is a particularly fluid, and in the case of fully automatic control, new development, the treatment is fairly brief.

In the second part a number of commercial instruments common to British melting shops is described under the following headings: "Pressure Meters," "High Temperature Pyrometers," "Single and Multipoint Recorders," "Automatic Control Systems." As elsewhere, the diagrams are outstandingly clear.

This is a book which can be thoroughly recommended. It achieves its main purpose of presenting a modern review of open-hearth instrumentation in clear language for the steelmaker, and is of good value to anyone else interested in the subject.—A. R. BAILEY

"*Die Metallwirtschaft der Schweiz und ihre Nebengebiete.*" 8vo, pp. 96. Zürich, 1951: Verlag für Wirtschaftsliteratur G.m.b.H. (Price 21*s.*)

This list of Swiss manufacturers and their products is compiled by the two Swiss founders' associations, the Verband Schweizerischer Eisengiessereien, of Zürich, and the Verband Schweizerischer Metallgiessereien, of Bern. Three lists, of iron and steel foundries, of brass and aluminium foundries, and of general foundries, are followed by a list of rolling mills and wire mills and the manufacturers of hard metals; then follow lists of the merchants of precious metals, of metals in ingot form and of metal products such as rails, roofing sheets, printing plates, ferro-alloys, extruded sections, etc., and finally, a list of scrap metal merchants. An alphabetical list of firms is provided, but it does not give their products.—J. P. S.

HEILIGENSTAEDT, W. "*Wärmetechnische Rechnungen für Industrieöfen.*" Stahleisen-Bücher Bd. 2. 3. Aufl. 8vo, pp. xv + 488. Illustrated. Düsseldorf, 1951: Verlag Stahleisen m.b.H. (Price DM 44.–)

The first edition of this work was published in 1935 in the form of a small pocket-size guide, for the designer and operator of furnaces in steelworks. The compact presentation of the theory and practical application of heat transfer made this a useful source of reference for those especially involved in solving the numerous heat-transfer problems encountered in steelworks practice.

The second edition which was published in 1945 was considerably enlarged in the form of a textbook.

The present edition, published in 1951, is a great improvement on the second edition. The fundamental theoretical data in Part A are practically the same but slightly expanded. Part B deals with the practical application of the theoretical calculations, and by numerous examples explains the solution of various problems arising in practice.

The author has simplified the work by means of graphs and tables, eliminating to a large extent lengthy calculations.

In Part A, Chapters 1 to 3 deal with the fundamental equations required as basic data for heat problems.

Chapter 4 goes into the thermal processes in the production of ferrous and also various non-ferrous metals, their specific heats, heat contents and heats of reaction, and the heat requirements in the making and treatment of iron and steel and also in the ceramic industry.

Chapter 5 discusses the theory of combustion with practical application to burners and furnaces, the definition of the burner coefficient and the determination of the combustion space.

Chapters 6 and 7 are concerned with the various modes of heat transfer and thermal conductivity.

Chapter 8 deals mainly with the heating of stock in batch furnaces and continuous furnaces, and with heat transfer in recuperators and regenerators.

Chapter 9 deals with special problems concerning the construction and operation of furnaces, the change in composition of gases on preheating, the use of protective atmospheres, and the theory of radiation tubes.

In Part B the application of the thermal calculations is explained. After a classification of furnace types and a description of the mode of calculating the heat consumption in Chapter 1, the remaining seven chapters deal individually with batch-heating furnaces; continuous heating furnaces; hearth-type furnaces, including steelmaking, copper-refining, and light-metal melting furnaces; large chamber-type furnaces, including ingot soaking pits; the blast-furnace; rotary furnaces; and blast-furnace stoves.

There is a considerable number of examples to explain practically every problem arising in this type of work.

His numerous publications have made Heiligenstaedt's name very well known in the iron and steel industry, and it is to be hoped that this further edition may be translated into English. This would be a welcome companion to A. Schack's book on "Industrial Heat Transfer."—J. W. REBER

INSTITUTE OF PHYSICS. "*Vacuum Physics.*" 4to, pp. 77. London, 1951: The Institute of Physics. (Price 15*s.*)

This consists of the papers given at a symposium on the subject, organized by the Midland Branch of the Institute of Physics in June, 1950. The papers cover vacuum pumps and gauges, industrial vacuum systems, methods of detecting leaks, and applications of vacuum methods in industry. These last include a paper on vacuum melting and sintering of metals.—J. P. S.

INTERNATIONAL COMMITTEE OF ELECTROCHEMICAL THERMODYNAMICS AND KINETICS. "*Proceedings of the Second Meeting of the International Committee of Electrochemical Thermodynamics and Kinetics.*" 8vo, pp. 408. Milan, 1951: Liberia Editrice Politecnica Cesare Tamburini. (Price 3800 lire.)

The meeting of which this is the record took place in Milan in September, 1950, with the participation of workers from many European countries and the United States. The papers are divided into sections: Electrochemical Equilibria, Electrochemical Kinetics, Application to Corrosion Studies, Application to General and Analytical Chemistry, Polarography, Nomenclature and Fundamental Definitions. Most of the papers are in French, a few are in English and a smaller number in German. Abstracts of those of interest to the ferrous metallurgist will appear in the *Journal*.—J. P. S.

MEDICAL RESEARCH COUNCIL. "*The Application of Scientific Methods to Industrial and Service Medicine.*" 8vo, pp. 112. London, 1951: H.M. Stationery Office. (Price 3*s*.)

This details the proceedings of a three-day conference on the applications of scientific methods in studies of industrial disease and of severe conditions in the Armed Services. At many points the importance of considering all the factors involved and of being sure that the factors considered are the correct ones is stressed. The occasional fallibility of animal studies—where it has been found that some chemical compounds are specifically poisonous only to rats—and the necessity of ensuring that laboratory studies reflect the usual exposure conditions are also emphasized. Of interest in this connection to metallurgists is the intrinsically poisonous nature of beryllium compounds; apparently non-poisonous if swallowed, they are extremely harmful if breathed into the lungs or introduced into cuts.

In considering the study of the effects of industrial conditions, the conference followed closely on the lines established by Mackworth in "Researches on the Measurement of Human Performance," reviewed in the *Journal* (1950, **166**, Oct., 167–168).—J. P. S.

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ANGLO-AMERICAN COUNCIL ON PRODUCTIVITY. "*Productivity Report. Metal Finishing.*" 4to, pp. xii + 75. Illustrated. London, 1951: The Council. (Price 3*s*. 6*d*.)

ANGLO-AMERICAN COUNCIL ON PRODUCTIVITY. "*Productivity Report. Saving Scarce Materials.*" 4to, pp. iv + 28. London, 1951: The Council. (Price 2*s*.)

ARIES, R. S., AND ASSOCIATES. "*Industrial Water Pollution.*" Pp. 142. Compiled by the staff of R. S. Aries and Associates. New York, 1951: Chemonomics, Inc. (Price $5)

BASHFORTH, G. REGINALD. "*The Manufacture of Iron and Steel.*" Volume 2: "*Steel Production.*" 8vo, pp. viii + 461. Illustrated. London, 1951: Chapman and Hall, Ltd. (Price 45*s*.)

BENBOW, W. E. "*Steels in Modern Industry.*" A comprehensive survey by 29 specialist contributors. General Editor: W. E. Benbow. 8vo, pp. viii + 562. Illustrated. London, 1951: Iliffe and Sons, Ltd. (Price 42*s*.)

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BRITISH STANDARDS INSTITUTION. B.S. 1780: 1951. "*Pressure Gauges.*" 8vo, pp. 56. London, 1951: The Institution. (Price 6*s*.)

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LANG, RUTH. "*Further Laboratory and Workshop Notes.*" A second selection reprinted from the *Journal of Scientific Instruments*. Compiled and edited by Ruth Lang for the Institute of Physics. 8vo, pp. xii + 290. Illustrated. London, 1951: Edward Arnold and Co. (Price 28*s*.)

MASING, GEORG. "*Grundlagen der Metallkunde in anschaulicher Darstellung.*" 3. Auflage. 8vo, pp. viii + 148. Illustrated. Berlin, 1951: Springer-Verlag. (Price DM 12.60)

MILLS, E. D. "*The Modern Factory.*" 4to, pp. 190. Illustrated. London, 1951: The Architectural Press. (Price 30*s*.)

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H.M. KING GEORGE VI

IT is with the deepest regret that the President and Council record the death of His Majesty King George VI on 6th February, 1952.

The King became Patron of the Institute in 1936.